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COMPOSITE MECHANICAL SIMULATION

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NASA

George C. Marshall Space Flight Center
Marshall Space Flight Center, Alabama

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By

H. T. Blaise

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ABSTRACT

This composite report describes the work accomplished within the first half of fiscal year 1968. It consists of data extracted from contractor progress reports concerning work performed in the development of mechanical space simulation.

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H. T. Blaise

MANUFACTURING ENGINEERING LABORATORY
RESEARCH AND DEVELOPMENT OPERATIONS

ACKNOWLEDGMENT

This publication is based on tests conducted in the Manufacturing Engineering Laboratory's mechanical simulation facility. Two reports contain results of out-of-house development of simulation equipment for in-house use. These principal tasks were the development of test procedures, evaluation testing, upgrading of simulators, design and manufacturing of related equipment, and release of final report. The requirements for design criteria and testing were established by R-ME-M, Mechanical Coordinator. Task Evaluation was performed by the Hayes International Corporation, MEL Operations, L-1, Space Experimentation Group. Design was conceived by R-ME-TD, Tool Design and Engineering Branch and out-of-house contractors.

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FOREWORD

In the latter part of fiscal year 1967 a plan was developed for upgrading the Manufacturing Research and Technology Division's zero and partial (1/6) gravity simulators as well as simulation techniques. Prior testing of various simulators had provided a "mean base" for further refinement within the then current design. The six-degree-of-freedom simulator testing revealed further need for minimizing frictional forces and to provide needed comfort to enable longer duration testing. In addition to these improvements, the adjustment of the test subject center of gravity was in need of a major upgrading. This was accomplished as evidenced within this document. The lunar gravity attachment for the five-degree-of-freedom simulator was found to be in need of design improvement both in center of gravity adjustment and improved comfort needed for longer duration testing. This improvement was accomplished except for the seating device. The current design of a form fitted fiberglas "cycle" seat should complete this upgrading.

Testing has revealed a need for additional improvements of the object work base on the zero and partial gravity simulators. Although attempts were made to upgrade its design configuration, it was found to be impractical. Tests indicated a need for elimination of side and horizontal impact forces caused by a "pendulum" like movement of the counter weight assembly. A refined model was successfully developed and tested as reported herein.

During preliminary testing of the five-link mechanical serpentuator during fiscal year 1967, it became evident that simulation techniques for providing a condition of "free flying" both for work objects and simulated space workers were needed. These simulators were developed and provide a work base for near frictionless translation and vertical adjustable positioning. In addition, this development provided a bonus simulation improvement in that platform flotation lifting height and load carrying can be adjusted by speed control of the blower motor. Levelness due to unbalanced loads is controlled by manual adjustment of valves at each air bearing. It was found that in some cases restriction of air was advantageous, in others a "controllable leak" was most effective. The "free flying" technique was added to the five-link serpentuator ("exserp") program of testing. The "exserp" testing continued to a realization of meaningful, possible use for close range extravehicular tasks, such as the removal of film cassettes, on the Apollo Telescope Mount (ATM) module. Further refinement of the "exserp" was attained by improvement of the mechanical hinge, up-powering of its motor gear box assembly, and modification of the control system providing infinite translation control. Various other items of support equipment and tools have been developed and tested and the test results will be outlined within this report.

DEVELOPMENT AND TESTING OF THE LUNAR GRAVITY AND EARTH ORBITAL SIMULATOR (PARALLELOGRAM)

Summary

This report contains an account of work accomplished in the development and testing of the Lunar Gravity and Earth Orbital Simulator or "Parallogram" (L/G and E/O).

The L/G and E/O was developed from specifications described within MSFC's Contract NAS8-20821, the Martin-Marietta Corporation, Baltimore, Maryland. Proof testing was accomplished at the contractor's plant under the surveillance of Air Force Inspection. In-house acceptance testing was accomplished in accordance with the requirements set forth by Technical Directive to the MEL Hayes Space Experiment Group. The work reports proof testing, irregularity of achieving balance of the L/G and E/O and the remedy of same.

Introduction

Development and test of Space Support Equipment requires evaluation of the problems inherent in working under the extraterrestrial gravities of weightless space, the lunar surface, and eventually planetary surfaces in order to identify and evaluate the possible solutions.

Under a contract to NASA, Martin Marietta began practical study of these problems in 1963 with the construction of a five-degree-of-freedom air bearing-supported frictionless simulator. This simulator was used to evaluate the need for special tools and techniques. Early work showed the need for improvements and simplification in the basic simulator design to make it a more efficient laboratory tool, and several of the improvements were incorporated in a simulator delivered to NASA-MSC in late 1963.

Need for a six-degree-of-freedom, vertical translation, was apparent and a concept of vertically translating the subject through a large volume air spring, plus unlimited rotational freedom, was incorporated in a six-degree-of freedom simulator installed by Martin Marietta at Wright Patterson Air Force Base in 1964.

A different approach, adapted to the study of work station rather than locomotion problems, was later developed in-house through the use of a frictionless parallelogram in conjunction with a five-degree-of-freedom simulator. This approach minimized the mass inherent in the six-degree-of-freedom simulator while allowing almost the same range of motion. It is particularly suited to lunar surface simulation where reduced rather than null gravity is required. This reduces the sensitivity of the simulator to subject balance changing as a result of work motions.

The parallelogram approach was chosen over other alternates on the basis of easy adjustment and the proven low friction capability of ball bearings under proper lubrication and loading conditions. The inherent drag hysteresis of cables and negator springs or other spring type devices plus their lack of adjustability and linearity and the relative expense of servo controlled devices were all considered in the choice of the parallelogram.

An improved five-degree-of-freedom simulator incorporating improved air bearings and a self-contained blower to reduce drag loads was delivered to NASA-MSFC in 1965.

In 1967, a parallelogram was developed to mate with this simulator and to provide additional flexibility of use through a demountable floor and an air bearing system to enable more sophisticated zero g testing.

Low Friction Parallelogram

GENERAL DESCRIPTION

The air bearing parallelogram is a parallelogram structure supporting a vertical task panel mount and removable floor and supported in turn on a rigid base on which are mounted three low friction air pads, an electrically powered blower and an air distribution system. The parallelogram structure can be counterweighted to balance the task panel so that low vertical forces will cause motion. Full details of construction can be determined from MSFC approved, Martin Marietta Drawing No. 861-00045.

The parallelogram exhibits low breakout forces of under 3 ounces (0. 83 N) in the vertical and horizontal directions. This permits the simulator to be used for 0-g testing as well as for reduced gravity testing.

Enough lead weight to counterbalance the platform and give 40 pounds (178 N) upward force to the astronaut was supplied with the simulator. Requirements specified enough extra weight to counterbalance the 200-pound (890-N) dead load during acceptance testing. Three 70-pound (312-N) lead pigs were supplied by the contractor for this purpose.

Only one problem was encountered with the hardware at Huntsville. One of the air pads was cocked so that one edge was 1/4 inch (0.635 cm) higher than the other. Removal of the air pad and examination of the system revealed the damage. The threaded rod supporting the pad had been bent. This was replaced and the acceptance tests were performed. The simulator performed satisfactorily in all respects.

TECHNICAL NOTES

NASA requested that curves be drawn showing the motor-blowing time/temperature relations to determine the relationship between air flow and temperature of motor with voltage control. These are included as Figures 1 through 4 of this report.

There is one minor peculiarity in the operation of this type of simulator. When the simulator is balanced vertically to any point in its operating range, it will remain at that point as expected. As little as 1 1/2 ounces (0.4 N) of force is required to break the static friction and initiate vertical motion. However, there is a slight restoring force which tends to return the platform to its initial balance position when the displacement force is removed.

Examination of the application of this simulator shows that this restoring action is not a problem and in most cases is a convenience. For instance, when used in the earth orbital mode a slight force will drive the work panel out of reach vertically, at which time the purpose or usefulness of the test has been fulfilled. The work panel will slow down and gradually return to its neutral position and testing can resume.

In the lunar gravity mode, the difference of a few ounces in the simulated weight of the astronaut from the standing to the stooping position will have virtually no effect on the simulation.

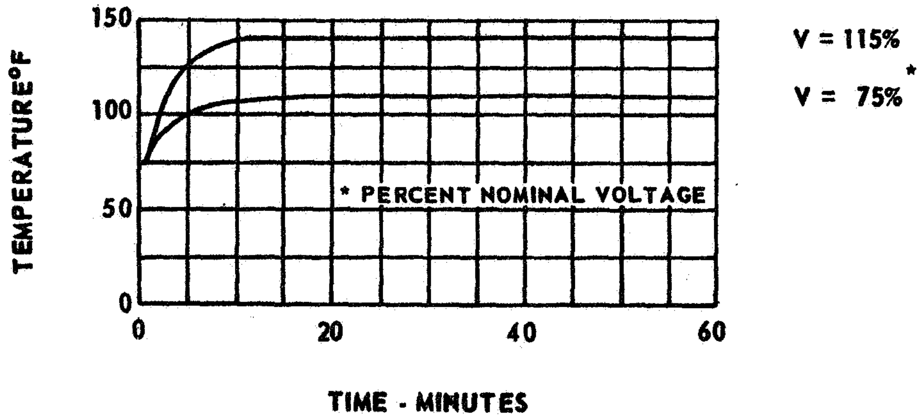

FIGURE 1. BLOWER SHROUD TEMPERATURE CURVES

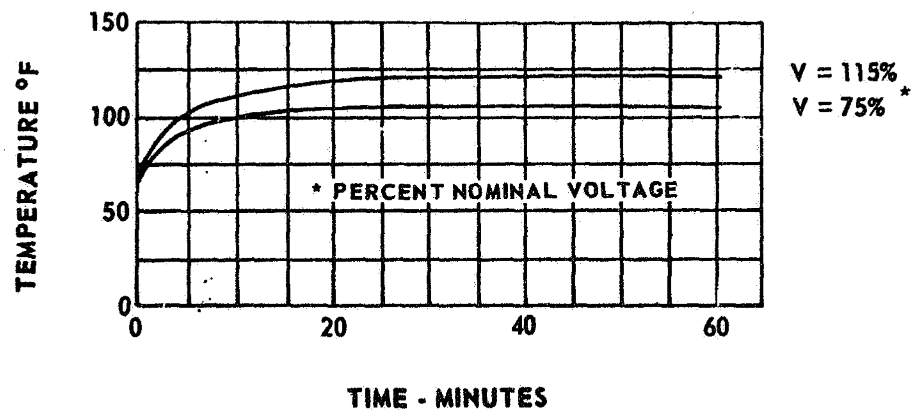

FIGURE 2. MOTOR STATOR TEMPERATURE CURVES

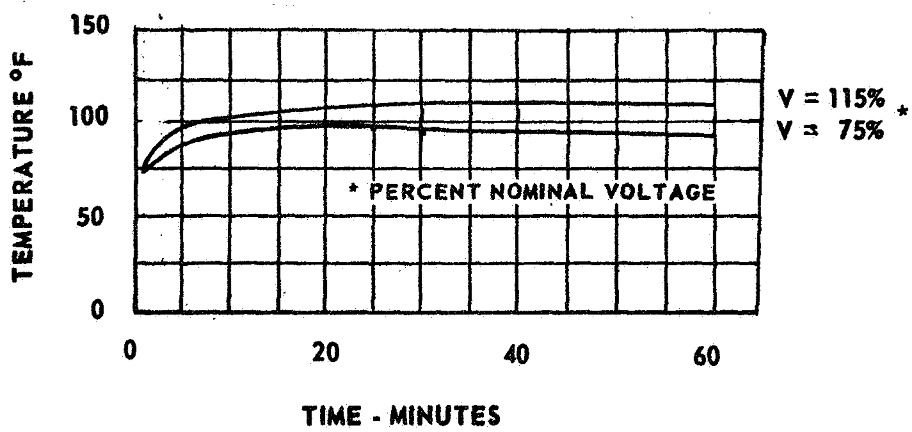

FIGURE 3. MOTOR SHROUD TEMPERATURE CURVES

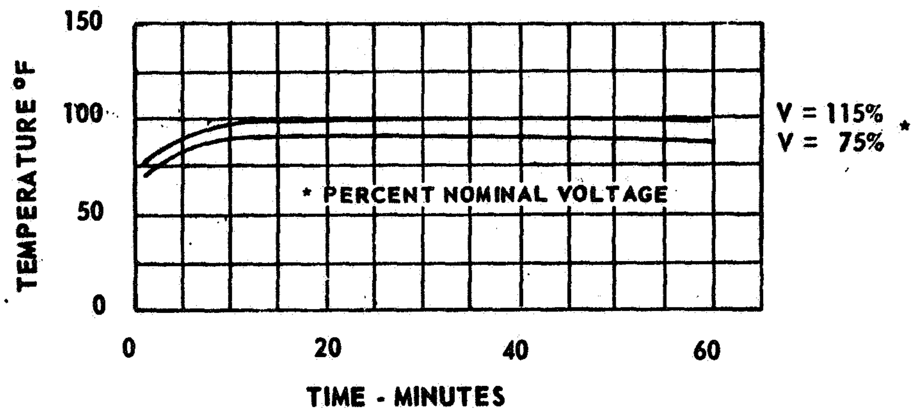

FIGURE 4. MOTOR TOP-BEARING TEMPERATURE CURVES

Preliminary analysis of the simulator geometry shows that a deflection as little as 0.010 inches (0.0254 cm) in the parallelogram arms, due to the weight of the counterbalanced load, will cause about 1 percent of the load to appear as a restoring force at the extremes of vertical travel. At the platform this force is proportional to the displacement from the neutral balance point. Hence, it is extremely low in the normal operating range.

Proof Testing of the Parallelogram

PURPOSE

The purpose of the proof testing procedure was to establish and demonstrate the capabilities of the air bearing parallelogram to meet the requirements of stability and breakout force specified in Contract NAS8-20821, Article I (Work Statement) and final acceptance test as specified herein.

TEST EQUIPMENT

Test equipment included:

1. Parallelogram structure, P/N 861-0045

2. Spring Balance 0-2 pound (0-8.9 N) horizontal and vertical reading

3. Lead Weights - Total 200 pounds (890 N)

4. Maintenance and Instruction Manual

TEST PROCEDURE

1. Vertical Friction Force Test

a. Set up.

(1) Using M&I Manual, install semi-circular platform.

(2) Balance by adjusting counterweight until floor remains in position to which it is set.

b. Test.

(1) With a spring balance measure maximum force required to initiate motion upward (Table I). Record 1 1/2 ounces (0.4 N).

(2) Repeat for downward motion. Record 1 1/2 ounces (0.4 N).

TABLE I. FORCE REQUIRED TO INITIATE MOTION

Trial No.	Force			
	Up		Down	
	Ounces	Newtons	Ounces	Newtons
1	1 1/2	0.4	1 1/2	0.4
2	1 1/2	0.4	1 1/2	0.4
3	1 1/2	0.4	1 1/2	0.4
4	1 1/2	0.4	1 1/2	0.4
5	1 1/2	0.4	1 1/2	0.4

NOTES: One of front air pads slightly out of parallel with floor due to bent threaded leg. However, this did not adversely affect performance of the simulator.

Trials performed with 70 percent Blower Motor Power, except when simulator was loaded with 200 pounds (890 N) weight. Motor Power of 100 percent was then required for air pads to have sufficient lift. This much power probably will not be required when out of parallel air pad is corrected.

(3) Repeat steps (1) and (2) five times each and compute average value. Acceptable value is any force less then 20 pounds (8.9 N). Record average value 1 1/2 ounces (0.4 N).

2. Horizontal Friction Force Test

a. Set up.

(1) Using M&I manual, install semi-circular platform.

(2) Balance by adjusting counterweight until floor remains in positions to which it is set.

(3) Assure that 115 VAC, 60 Hz power source is connected to blower power connector.

b. Test.

(1) Turn power on.

(2) Adjust the variable transformer until the air pads inflate and lift assembly approximately 1/4 inch (0.635 cm).

(3) If required, adjust air pad valves to balance fit.

(4) With a spring balance, apply horizontal forces to floor assembly or work panel mounting structure to initiate motion.

(5) Verify that horizontal force is well below 2.0 pounds (8.9 N). Record value 2 ounces (0.6 N). Note: Depending upon floor levelness, the force should be less than 4 ounces (1.1 N). Assembly may move of its own accord, coasting to lowest point on the floor.

3. Vertical Load 200 Pound (890 N) Proof Test

a. Set up.

(1) Using M&I manual, set up on smooth floor.

(2) Assure that blower power is off.

(3) Install semi-circular platform.

(4) Assure that support legs are fully extended.

(5) Remove weights in counterweight to assure that platform is at lowest point.

b. Test.

(1) Apply a 200 pound (890 N) weight to rear center of platform.

(2) Attach counterweights until platform legs just lift off floor.

(3) Turn on air pad blower and adjust variable transformer until air pads inflate and lift assembly 1/4 inch (0.635 cm).

(4) Apply horizontal force to move parallelogram across floor.

(5) Observe that structure is stable under load and moves horizontally with no interference. If interference is noted, check air pad flotation height and adjust air pad valves to balance lift.

Irregularities of the Simulator

As indicated previously in this report, true balance of the simulator had not been achieved. Since true balance is necessary to achieve earth orbital simulation, the irregularity was undesirable. An investigation was made to determine the true cause of the irregularity.

Manufacturing Engineering Laboratory personnel optically aligned and measured the simulator. All measurements were verified by Quality and Reliability Assurance Laboratory personnel. The optical measurement findings indicated that the simulator was out of tolerance to a minor degree.

The Martin Corporation's analysis for the simulator's peculiarity in that a deflection of 0.010 inch (0.0254 cm) in the parallelogram arms due to the weight of the counterbalance load will cause 1 percent of the load to appear as a restoring force at the extremes of vertical travel (either the ultimate top or bottom locations). Assuming this analysis was correct and with the additional information of optical measurements taken, the following testing and conclusion were offered for consideration.

The parallelogram was tested for restoring forces. Maximum restoring forces for parallelogram from bottom to top or top to bottom is 2 pounds (8.9 N) for the balanced parallelogram without platform. Assuming that 1 percent of the counterbalanced beam weight is included in these 2 pounds (8.9 N), 2 pounds minus (1 percent of 70 pounds) = 1.3 pounds (5.8 N) restoring force. The 2 percent additional restoring force was believed due to the parallelogram being slightly out of parallel with some dimensions being slightly out of tolerance.

These test data were analyzed and further calculations resulted in a modification to the L/G and E/O which was totally effective in resolving the balancing peculiarity.

Calculations for Simulator Modification

Figure 5 shows the geometry of the restoring force problem and the corrections applied. It is assumed that the restoring forces is a pendulous effect due to the effective center of gravity of the parallelogram and counterweights being below the center of the bearings by some distance, ϵ. When the platform is moved to either limit the arms rotate to about 22 degrees from horizontal. The weight, W, creates a restoring moment, M_r, as it moves through an angle, Θ, which is:

$$M_r = W \epsilon \sin \Theta .$$

It is this moment which we must balance out. A force, f_2, applied vertically to arm l will give a cancelling moment M_c of:

$$M_c = - f_1 l \sin \Theta .$$

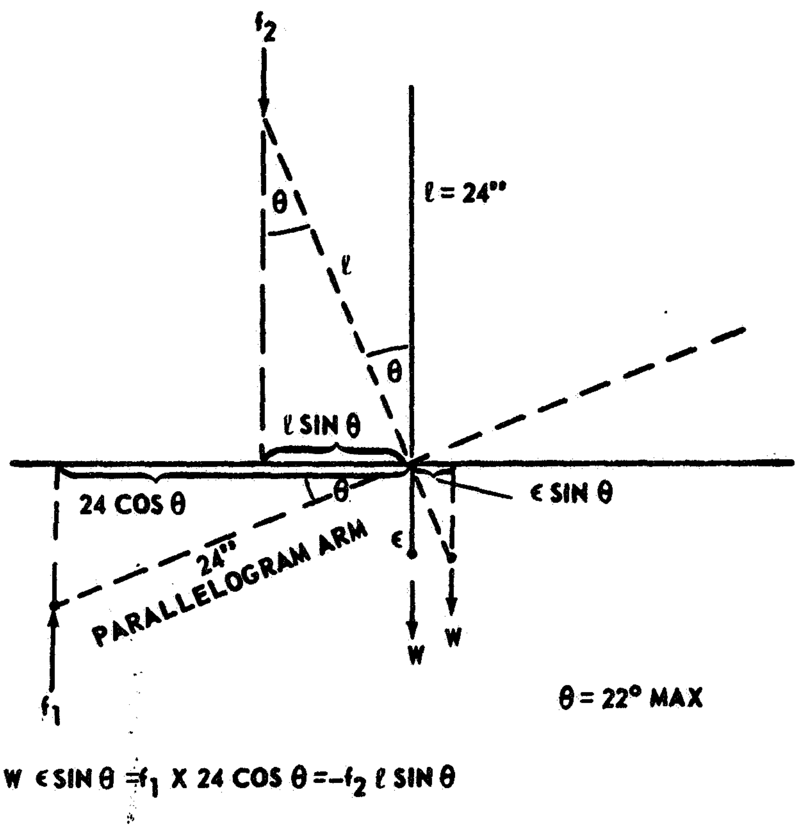

FIGURE 5. CANCELLATION MECHANISM GEOMETRY

Assume we wish to cancel a six-pound (26.7 N) restoring force f_1 on the platform. The simulator moment arms are 24 inches (0.61 m) long so that the moment on the parallelogram at the maximum 22 degree angle is:

$$f_1 \times 24 \cos 22 \text{ degrees} = 6 \times 24 \cos 22 \text{ degrees} = 132 \text{ inch-pounds } (14.9 \text{ Nm}).$$

If we choose an arbitrary length of 24 inches (0.61 m) for the cancelling arm l (based on available space and loading considerations) the weight, f_2, required will be:

$$f_2 = \frac{132 \text{ inch-pounds}}{24 \sin 22 \text{ degrees inches}} = \frac{132}{9.0} = 14.6 \text{ pounds } (65.0 \text{ N})$$

Since lead has a volume of about 2.44 cubic inches per pound (88.2 cm^3/kg), about 35.5 cubic inches (581 cm^3) of lead are required for the weight. Figure 6 shows the dimensions chosen for the weight. The length of the aluminum tube was chosen to be 26 inches (0.66 m) to allow the center of the weight to be placed about the 24-inch (0.61 m) level for additional connection, if required. Note that the length l used in the calculations would be measured from the center of the bearing to the combined center of mass of the tubing and the weight.

Adjustment of Cancelling Device

The cancelling device should be adjusted in accordance with the following steps:

1. The weight should be removed. The simulator and its load should then be balanced as per the maintenance manual instructions, but with the parallelogram arms horizontal. The weight should be replaced on the cancelling device at about its correct height for the load.

2. Rotate the weight to a point where the arms remain horizontal.

3. The parallelogram floor should then be pressed down to its bottom position and the cancelling weight moved up or down until the restoring force is just cancelled. (A +, -, or 0 force may be achieved.)

4. At this point the parallelogram should be returned to horizontal position and step 2 repeated.

5. Check for minimum unbalances through the range of vertical motion of the parallelogram and repeat steps 2, 3, and 4 for optimum results.

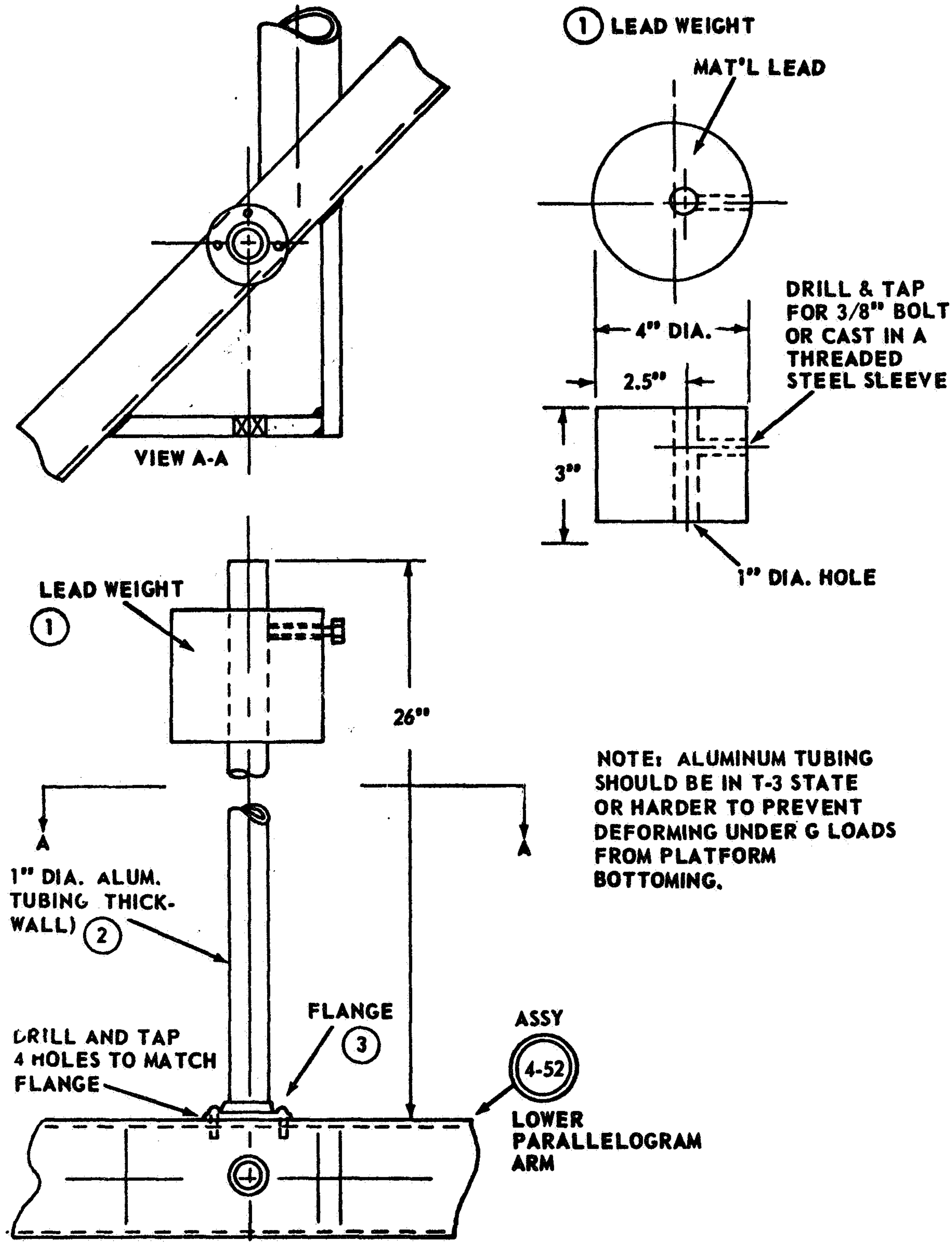

FIGURE 6. CANCELLATION MECHANISM

EVALUATION OF MECHANICAL SIMULATION TASK BOARDS

Summary

This report contains a proposed MEL Engineering Test Plan and the basic procedures for use in the control of tests conducted with the three mechanical simulation task boards. Included with operating procedures and safety precautions are specific data concerning the accessibility to each work station, the versatility of each work station and the ability of each work station to simulate space vehicle components.

The work described in this evaluation of mechanical simulation task boards was conducted by Hayes International Corporation, under Technical Directive R-ME-MM-9, Project Number 0392. The results of this work were published in MEL Technical Reports SE-9-67 and SE-35-67.

INTRODUCTION

Three mechanical simulation task boards containing mechanical, electrical, and hydraulic components have been designed and fabricated to support tests conducted with the five-degree- and six-degree-of-freedom simulators. The boards are constructed of 0.02 m (0.75 in.) plywood and are 2.4 m (8 ft) long and 1.2 m (4 ft) wide. Each board has a handrail which extends along the bottom edge and one half the way up the edges on each side. A 0.15 m (6 in.) shelf extending the length of each board has been attached to the extreme bottom edge. Eye bolts have been positioned at various points on each board so that an operator can be tethered near each work station.

The boards have been mounted on wood "A frames" (Fig. 7) which provide vertical positioning. Boards 1 and 2 have been mounted on opposite sides of one "A frame" and board 3 has been mounted opposite a blank board on another "A frame."

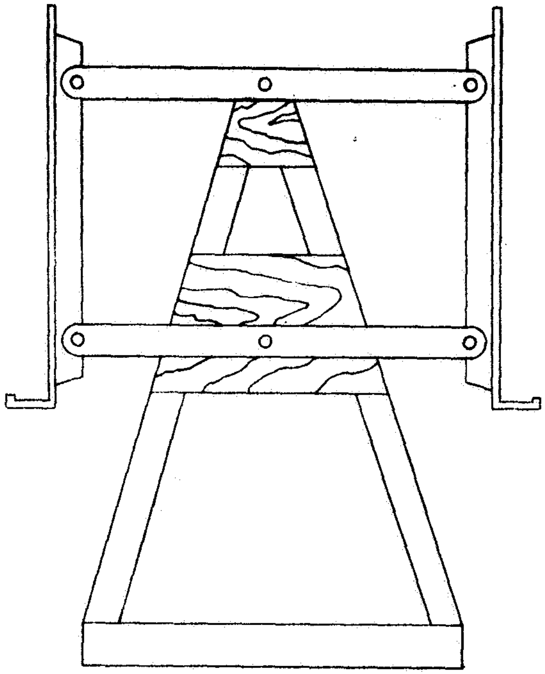

FIGURE 7. TASK BOARD ARRANGEMENT

Purpose

The purpose of this project is to evaluate the three mechanical simulation task boards to determine their ability to simulate tasks. The data generated will be used to determine the adequacy of the boards to evaluate future astronaut activities and new space tools.

Discussion

The three mechanical simulation task boards have been designed and fabricated to support tests using the five-degree- and six-degree-of-freedom simulators. These task boards provide open and recessed work stations which include mechanical, hydraulic, and electrical simulated space tasks.

This plan will outline the methods and procedures to be used for evaluating each task board's capability to simulate specific test problems which include

a. Operating procedures
b. Safety precautions
c. Accessibility to work stations
d. Versatility of work stations

The equipment required in addition to the three task boards is the six-degree-of-freedom simulator, an Arrowhead pressure suit, and assorted hand tools.

REQUIRED ACTION

The boards will be evaluated by positioning a test subject in a working position for each task. Where applicable, tools which have a proven history will be used to remove and replace working components or to perform specific tasks. The tasks will be performed by at least two different test subjects in shirt sleeve and pressurized environments in the six-degree-of-freedom simulator. Restraints, interference between tasks, hand holds, and work positions will be observed and recorded along with specific data for each task. The proposed sequence for evaluation of each task board is presented in Table II.

Evaluation Procedure

Data were gathered by positioning a test subject at each work station and performing the required task. All tasks, except those which require hands only, were performed with tools which have a proven history.

Operators noticed no severe safety hazards while performing the tasks pressurized or unpressurized. However, due to the several metal projections on the boards, it is suggested that operators wear safety helmets at all times.

Each work station was found to have ample clearance between adjacent work stations while performing the required tasks. Tether points were located near each work station but can be relocated if necessary. Board #3 has several electrical components yet to be installed; therefore, it is recommended that actual working parts be used in order to better simulate space tasks.

TASK BOARD #1

Board #1 (Fig. 8) was designed to provide the three test conditions described below:

a. Station 1 contains an off-balanced, light weight instrument compartment 0.07 m(3 in.) by 0.25 m (10 in.) by 0.41 m (16 in.) on an enclosed shelf within the test board. The location of the compartment causes operators to become slightly off balance while removing or replacing objects with both hands.

b. Station 2 consists of a valve adjustment task to simulate the simultaneous adjustment of two controls. The right control has a lever arm type and the left control has a knob type device. The object of the adjustment problem is to center a small disc reticle within a "bull's eye" fixture.

TABLE II. TASK BOARD EVALUATION SEQUENCE

Sequence	Task Description	Required Tools
	Board #1	
1.	Remove and replace off balance object.	Hands only
2.	Perform valve adjustment task.	Hands only
3.	Remove and replace "fall away" man hole cover	Hands only
	Board #2	
1.	Perform drilling task with sheet aluminum.	$\frac{1}{4}$" drill motor with required drill size
2.	Perform sawing operation with horizontal and vertical mounts using sheet aluminum.	Air operated "Nibbler"
3.	Perform drilling operation using plate aluminum with vertical mount.	$\frac{1}{4}$" drill motor with required drill size
4.	Perform hammering task with sheet aluminum.	$\frac{1}{2}$ pound hammer
5.	Remove and replace manhole cover.	Fly-ball tool with 9/16" socket
	Board #3	
1.	Remove and replace box detail	Sears ratchet $\frac{1}{4}$" socket, screwdriver
2.	Disassemble and assemble hydraulic connections at three different locations. Record individual times.	9/16" ratcheting open end wrench
3.	Remove and replace tube flange assembly.	$\frac{1}{2}$" ratcheting open end wrench
4.	Remove and replace wires from terminal block.	Screwdriver
5.	Disassemble and assemble hydraulic valve connections. Perform valve adjustment task.	9/16" ratcheting open end wrench
6.	Perform plug-in task.	Hands only
7.	Remove and replace relay bracket assembly.	Screwdriver
8.	Remove hatch cover to recessed work station.	Hands only
9.	Remove and replace recessed electrical and hydraulic components.	Screwdriver, 9/16" open end ratcheting wrench
10.	Replace hatch cover to recessed work station.	Hands only

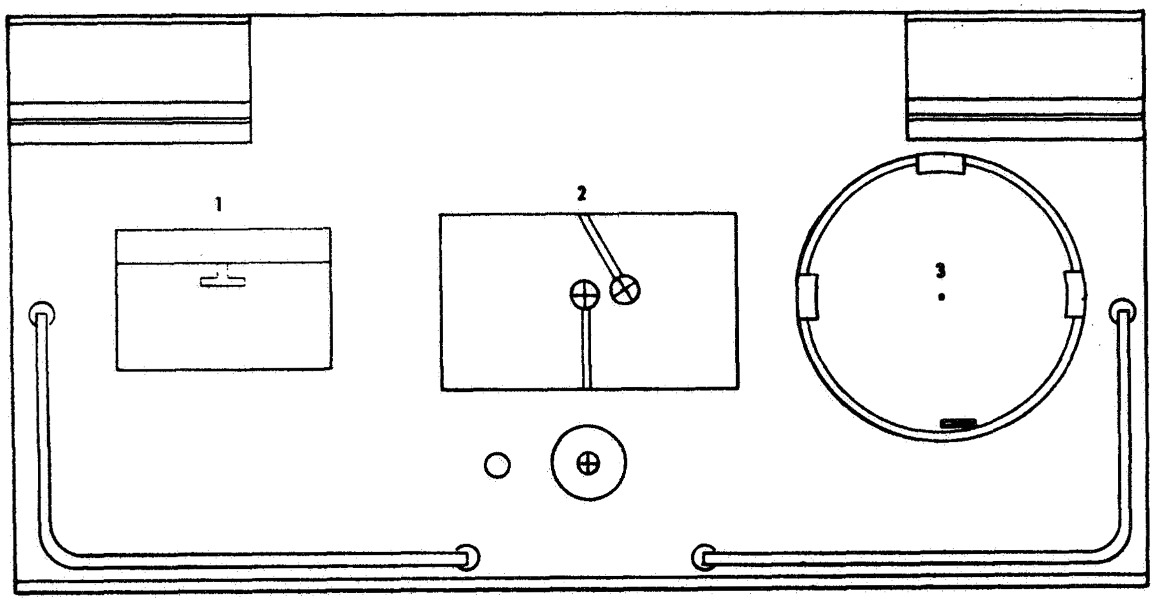

FIGURE 8. TASK BOARD #1

c. Station 3 contains a light weight manhole cover approximately 0.61 m (24 in.) in diameter. The manhole base, permanently located on the test board, has three slotted guides and a locking pin to hold the cover in place. When unfastened, the "manhole" cover tends to fall away requiring the operators to use both hands to retain the cover.

TASK BOARD #2

Board #2 (Fig. 9) was designed to provide work stations for the following simulated space tasks:

a. Station 1 consists of a mounting bracket used for drilling up to 0.003 m (0.125 in.) holes in a 0.31 by 0.31 m (12 by 12 in.) flat sheet and plate material and is positioned with approximately a 0.1 m (4 in.) stand-off from the board. A 0.008 m (0.25 in.) hinged aluminum plate cover with six small drill guides is used as a means for clamping the test article. The drill guides are provided with replaceable bushing inserts to prevent marring of the hinged aluminum plate while drilling.

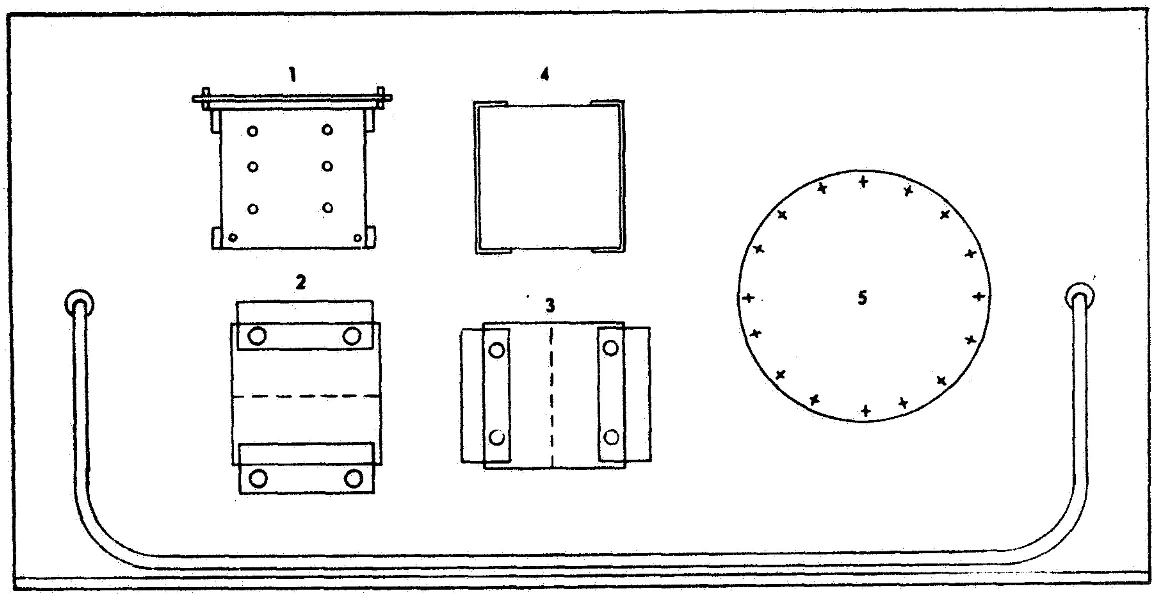

FIGURE 9. TASK BOARD #2

b. Stations 2 and 3 are used for sawing or drilling 0.31 by 0.31 m (12 by 12 in.) flat sheet and plate material. Station 2 mounting brackets are positioned horizontally and Station 3 mounting brackets are positioned vertically. Each bracket provides approximately 0.1 m (4 in.) stand-off from the board for the test articles. This is considered ample clearance for most sawing and drilling operations. Plate material up to 0.006 m (0.25 in.) thick could be mounted in the bracket as test articles.

c. Station 4, a hammering task, consists of two aluminum "Z" bars positioned vertically 0.24 m (9.5 in.) apart. The bars are positioned enabling a thin sheet material to be "C" clamped to the inside legs. The outside edges are formed around the radius of the "Z" bars using a conventional hammer. While hammering, care should be taken not to mar the surface of the "Z" bar radius.

d. Station 5 is used as a manhole cover removal and assembly task. The cover is attached to the manhole flange with 16 bolts. To provide optimum ease in replacing the cover, the bolt holes should be aligned in the same position as they were when the cover was removed. The holes are not equally spaced.

TASK BOARD #3

Board #3 (Fig. 10) was designed to provide mechanical, hydraulic, and electrical work stations as follows:

a. Station 1 contains a black box removal and replacement task. The box is attached to the board with an aluminum mounting bracket and two bolts. The box is 0.08 by 0.1 by 0.15 m (3 by 4 by 6 in.) and is fabricated of 0.025 m (1 in.) lumber.

b. Station 2 contains three hydraulic assemblies of 0.006 m (0.25 in.) stainless steel tubing. The assemblies are described as follows:

1. "U" shaped with two connections

2. "Square" shaped with four connections

3. "Semi-square" shaped with two connections

All connections are spaced approximately 0.1 m (4 in.) from the work board.

c. Station 3 is a "U" shaped 0.025 m (1 in.) stainless steel tube flange assembly. The center section of the flange assembly, positioned approximately 0.13 m (5 in.) from the board, is held in place by eight bolts which are threaded into the center section flange.

d. Station 4, a wiring fixture, contains two terminal blocks positioned horizontally and space approximately 0.20 m (8 in.) apart. The terminal blocks can accept a total of 24 wires from a wire cable located near the blocks.

e. Station 5 contains a hydraulic task assembly with six connections. The assembly is mounted on an aluminum bracket spaced approximately 0.022m (0.875 in.) from the board.

These connections are similar to the hydraulic connections at station 2; therefore, it is suggested that the existing simulated valve adjustment fixture be replaced with a working valve which can be manipulated by an operator. By making this change, additional data can be gathered without repetition of tasks.

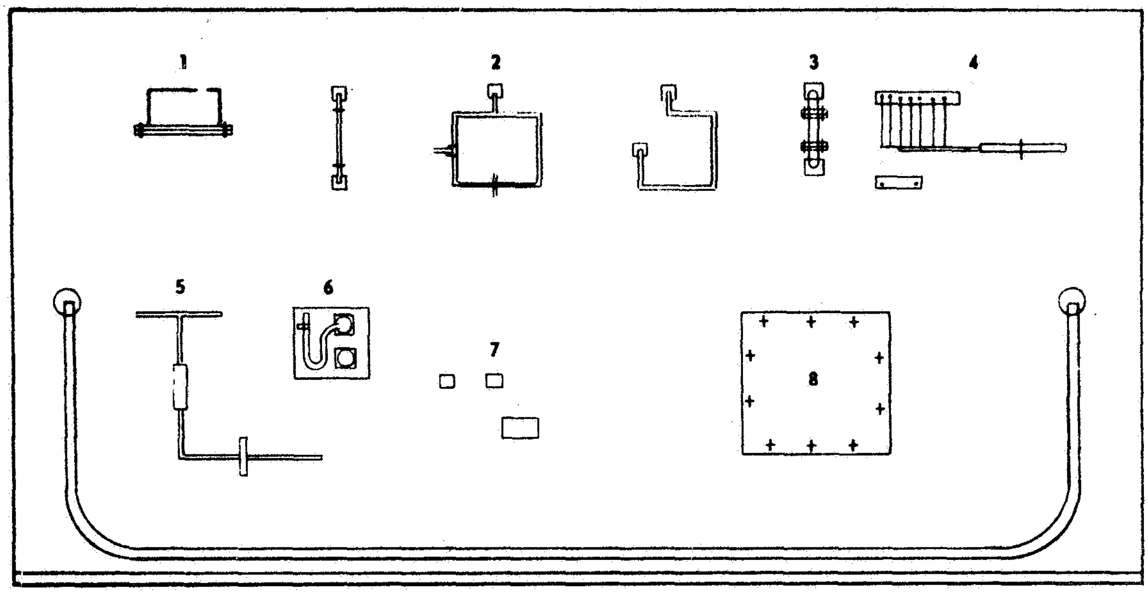

FIGURE 10. TASK BOARD #3

f. Station 6 is a "plug in" hand thread nut coupling cable assembly.

g. Station 7, a relay bracket assembly, was not evaluated because the station had not been completed.

h. Station 8 consists of a removable hatch cover and a recessed work station. The hatch cover is held in place by ten cam locks which are permanently attached to the cover. The recessed work station contains both electrical and hydraulic components which were not fully completed at the time of testing and therefore no evaluation was made.

CONCLUSIONS AND RECOMMENDATIONS

Operators indicated each work station had ample clearance between adjacent work stations while performing the required task.

No severe safety hazards were noted while performing the tasks pressurized or unpressurized. However, due to several metal projections, operators should wear safety helmets at all times while working near the boards. Several tether points have been located near each work station but can be relocated by drilling through the board and installing the desired eye bolts. The tether points should be relocated only when necessary.

Board #3 has several electrical components to be installed; therefore, it is suggested that actual working parts be used. By installing working parts, operators can better evaluate future space tools for specific tasks.

The results of this evaluation are presented in Tables III through XIV.

TABLE III. TASK BOARD #1
(Williams - Shirtsleeve)

Station	Time (sec)	Tools Required	Comments
1. Off-balanced object	Off - 22 On - 43	Hands Only	Removing process caused subject to become off-balanced.
2. Valve adjustment task	Trial #1 - 09 Trial #2 - 07	Hands Only	
3. Manhole Cover	Off - 03 On - 62	Hands Only	Removing process caused subject to become off-balanced.

TABLE IV. TASK BOARD #1
(Hunter - Shirtsleeve)

Station	Time (sec)	Tools Required	Comments
1. Off-balanced object	Off - 15 On - 21	Hands Only	Removing process caused subject to become off-balanced.
2. Valve adjustment task	Trial #1 - 08 Trial #2 - 03	Hands Only	
3. Manhole Cover	Off - 03 On - 13	Hands Only	Removing process caused subject to become off-balanced.

TABLE V. TASK BOARD #1
(Williams - Pressurized)

Station	Time (sec)	Tools Required	Comments
1. Off-balanced object	Off - 31 On - 78	Hands Only	Removing process caused subject to become off-balanced.
2. Valve adjustment task	Trial #1 - 11 Trial #2 - 09	Hands Only	
3. Manhole Cover	Off - 03 On - 46	Hands Only	Removing process caused subject to become off-balanced.

TABLE VI. TASK BOARD #1
(Hunter - Pressurized)

Station	Time (sec)	Tools Required	Comments
1. Off-balanced object	Off - 39 On - 69	Hands Only	Removing process caused subject to become off-balanced.
2. Valve adjustment task	Trial #1 - 05 Trial #2 - 09	Hands Only	Removing process caused subject to become off-balanced.
3. Manhole Cover	Off - 04 On - 40	Hands Only	Removing process caused subject to become off-balanced.

TABLE VII. TASK BOARD #2
(Williams - Shirtsleeve)

Station	Time (sec)	Tools Required	Comments
1. Drilling	Trial #1 - 53 (6 holes) Trial #2 - 41 (6 holes)	$\frac{1}{4}$" Drive Drill Motor - 1/8" Drill	
2. Sawing	Trial #1 - 13 Trial #2 - 14	Air operated "Nibbler"	
3. Drilling	Trial #1 - 241 (6 holes)	$\frac{1}{4}$" Drive Drill Motor - $\frac{1}{4}$" Drill	Holes drilled at random
4. Hammering	Trial #1 - 72 Trial #2 - 54	0.23 kg (0.5 lb) Hammer	
5. Manhole Cover - Removal and Re-placement	Off - 243 On - 414	"Flyball Tool with $\frac{1}{2}$" Socket	

TABLE VIII. TASK BOARD #2
(Hunter - Shirtsleeve)

Station	Time (sec)	Tools Required	Comments
1. Drilling	Trial #1 - 35 (6 holes) Trial #2 - 27 (6 holes)	$\frac{1}{4}$" Drive Drill Motor - 1/8" Drill	
2. Sawing	Trial #1 - 07 Trial #2 - 03	Air operated "Nibbler"	
3. Drilling	Trial #1 - 360 (6 holes)	$\frac{1}{4}$" Drive Drill Motor - $\frac{1}{4}$" Drill	Holes drilled at random
4. Hammering	Trial #1 - 80 Trial #2 - 45	0.23 kg (0.5 lb) Hammer	
5. Manhole Cover - Removal and Re-placement	Trial #1 - 515 Trial #2 - 740	"Flyball" Tool with $\frac{1}{2}$" Socket	Difficult to replace due to alignment problems

TABLE IX. TASK BOARD #2
(Williams - Pressurized)

Station	Time (sec)	Tools Required	Comments
1. Drilling	Trial #1 - 69 (6 holes) Trial #2 - 76 (6 holes)	$\frac{1}{4}$" Drive Drill Motor - 1/8" Drill	
2. Sawing	Trial #1 - 32 Trial #2 - 39	Air operated "Nibbler"	
3. Drilling	Trial #1 - 269	$\frac{1}{4}$" Drive Drill Motor - $\frac{1}{4}$" Drill	Holes drilled at random
4. Hammering	Trial #1 - 123 Trial #2 - 101	0.23 kg (0.5 lb) Hammer	
5. Manhole Cover - Removal and Re-placement	Off - 320 On - 463	"Flyball" Tool with $\frac{1}{2}$" Socket	Difficult to replace due to alignment problems

TABLE X. TASK BOARD #2
(Hunter - Pressurized)

Station	Time (sec)	Tools Required	Comments
1. Drilling	Trial #1 - 49 (6 holes) Trial #2 - 62 (6 holes)	$\frac{1}{4}$" Drive Drill Motor - 1/8" Drill	
2. Sawing	Trial #1 - 16 Trial #2 - 21	Air operated "Nibbler"	
3. Drilling	Trial #1 - 419 (6 holes)	$\frac{1}{4}$" Drive Drill Motor - $\frac{1}{4}$" Drill	Holes drilled at random
4. Hammering	Trial #1 - 135 Trial #2 - 179	0.23 kg (0.5 lb) Hammer	
5. Manhole Cover - Removal and Replacement	Trial #1 - 552 Trial #2 - 860	"Flyball" Tool with $\frac{1}{2}$" Socket	Difficult to replace due to alignment problems

TABLE XI. TASK BOARD #3
(Hunter - Shirtsleeve)

Station	Time (sec)	Tools Required	Comments
1. Box Removal & Replacement	Off - 47 On - 50	Two 3/8" Wrenches	Two hands required
2. Hydraulic Connections			
a. "U-Shaped"	Off - 39 On - 19	9/16" & 11/16" Open-end Wrenches	Two hands required
b. "Square shaped"	Off - 109 On - 160	9/16" & 11/16" Open-end Wrenches	Two hands required
c. "Semi-square shaped"	Off - 84 On - 16	9/16" & 11/16" Open-end Wrenches	Two hands required
3. Tube Flange Assembly	Off - 186 On - 179	Sears Ratchet - 5/16" Allen	Two hands required
4. Electrical Connections	Off - 100 On - 170	Screwdriver	Two hands required (29 connections)
5. Hydraulic Valve Connection	Off - 39 On - 99	9/16" & 11/16" Open-end Wrenches	Two hands required
6. "Plug-in" Assembly	Off - 07 On - 17	Hands only	One hand required
7. Hatch Cover	Off - 13 On - 15	Hands Only	Two hands required One lock would not release

TABLE XII. TASK BOARD #3
(McClure-Shirtsleeve)

Station	Time (sec)	Tools Required	Comments
1. Box Removal and Replacement	Off - 26 On - 41	Two 3/8" Wrenches	Two hands required
2. Hydraulic Connections			
a. "U-shaped"	Off - 28 On - 13	9/16" & 11/16" Open-end Wrenches	Two hands required
b. "Square-shaped"	Off - 39 On - 69	9/16" & 11/16" Open-end Wrenches	Two hands required
c. "Semi-square shaped"	Off - 18 On - 18	9/16" & 11/16" Open-end Wrenches	Two hands required
3. Tube Flange Assembly	Off - 120 On - 174	Sears Ratchet - 5/16" Allen	Two hands required
4. Electrical Connections	Off - 79 On - 273	Screwdriver	Two hands required (29 connections)
5. Hydraulic Valve Connection	Off - 77 On - 74	9/16" & 11/16" Open-end Wrenches	Two hands required
6. "Plug-in" Assembly	Off - 08 On - 13	Hands Only	One hand required
7. Hatch Cover	Off - 12 On - 20	Hands Only	Two hands required One lock would not release.

TABLE XIII. TASK BOARD #3
(Williams - Pressurized)

Station	Time (sec)	Tools Required	Comments
1. Box Removal & Replacement	Off - 69 On - 183	Two 3/8" Wrenches	Two hands required
2. Hydraulic Connections			
a. "U-shaped"	Off - 44 On - 39	9/16" & 11/16" Open-end Wrenches	Two hands required
b. "Square shaped"	Off - 129 On - 192	9/16" & 11/16" Open-end Wrenches	Two hands required
c. "Semi-square shaped"	Off - 40 On - 64	9/16" & 11/16" Open-end Wrenches	Two hands required
3. Tube Flange Assembly	Off - 364 On - 466	Sears Ratchet - 5/16" Allen	Two hands required
4. Electrical Connections	Off - 110 On - 178	Screwdriver	Two hands required (29 connections)
5. Hydraulic Valve Connection	Off - 110 On - 147	9/16" & 11/16" Open-end Wrenches	Two hands required
6. "Plug-in" Assembly	Off - 20 On - 40	Hands Only	One hand required
7. Hatch Cover	Off - 14 On - 27	Hands Only	Two hands required One lock would not release

TABLE XIV. TASK BOARD #3
(Stephenson - Pressurized)

Station	Time (sec)	Tools Required	Comments
1. Box Removal & Replacement	Off - 41 On - 79	Two 3/8" Wrenches	Two hands required
2. Hydraulic Connections			
a. "U-shaped"	Off - 50 On - 88	9/16" & 11/16" Open-end Wrenches	Two hands required
b. "Square-shaped"	Off - 72 On - 178	9/16" & 11/16" Open-end Wrenches	Two hands required
c. "Semi-square shaped"	Off - 42 On - 43	9/16" & 11/16" Open-end Wrenches	Two hands required
3. Tube Flange Assembly	Off - 192 On - 242	Sears Ratchet 5/16" Allen	Two hands required
4. Electrical Connections	Off - 140 On - 283	Screwdriver	Two hands required (29 connections)
5. Hydraulic Valve Connection	Off - 133 On - 169	9/16" & 11/16" Open-end Wrenches	Two hands required
6. "Plug-in" Assembly	Off - 12 On - 14	Hands Only	One hand required
7. Hatch Cover	Off - 18 On - 23	Hands Only	Two hands required One lock would not release

UPGRADED LUNAR GRAVITY SIMULATOR

Summary

The five-degree-of-freedom simulator was upgraded to provide a capability of performing lunar gravity simulation with minimum test subject restraint. Early design concepts of the five-degree-of-freedom simulator used a stiff body cradle which limited the test subject's freedom of movement to arms and head. The upgraded five-degree-of-freedom lunar simulator utilizes a bicycle seat and additional body restraints, leaving the legs and feet free. The upgrading was conducted under Technical Directive R-ME-MM-10 by Hayes International Corp., and data for this report obtained from MEL reports SE-11-67 and SE-26-67.

Conversion Hardware

The conversion apparatus consists of a bicycle seat, back supports, restraint straps, two bearing pivot points in the pitch plane, and stops to prevent pitch rotation in excess of 160 degrees.

Each of the two bearing pivot points has a provision for two machine bolts for mounting the conversion unit to a "Y" section yolk. Removal and replacement of these four bolts using only an Allen wrench and a socket wrench is easily accomplished by one person if the unit is supported during the operation. The necessary support can be obtained by suspending the apparatus from overhead or by the assistance of a second technician. Removal and replacement time for the conversion is approximately ten minutes.

The aluminum stops which limit rotation are adequately strong and well placed. It is possible for the subject to rotate through a sufficient number of degrees to execute any planned exercise but at the same time is restrained by the stops to prevent injury to himself or to equipment.

The restraint straps are placed to restrain the test subject regardless of attitude. All five belts are of adequate length and thickness and are equipped with automotive type, metal to metal, quick release buckles. The buckles can be released by a pressurized glove. There is no danger of the test subject releasing the buckles accidently resulting in injury because release of a single restraint strap will not allow the test subject to fall.

The back supports consist of four curved aluminum plates which cradle the test subject and provide back support. Each plate is adjustable from left to right and is secured by three knurled screws. While the magnitude of the adjustment is quite satisfactory, it is difficult to tighten the adjusting screws sufficiently without the aid of pliers to prevent movement of the back support.

The present personnel seat is a commercial bicycle seat and is adequately adjustable for height, horizontal rotation, and fore and aft tilt.

Equipment Adjustment

Adjustment of the conversion unit is similar to adjustments of the original stiff body cradle except that it is more time consuming to properly balance the test subject. Freedom of movement allowed the test subject by not restraining the legs and feet makes balancing a fluid body more difficult, as opposed to balancing a rigid body. Time for the balancing operation has increased from approximately ten to thirty minutes with amount of adjustment available adequate in both planes.

Despite careful balancing there exists two attitudes in the pitch plane from which the test subject can not always recover. These points are at either extreme of pitch rotation and will never be entered into during any serious exercise.

Lunar Gravity Simulation

The upgraded lunar gravity simulator was evaluated by using the recently obtained parallelogram task board equipped with the semi-circular foot board to simulate lunar gravity. Balancing of the task board was accomplished by counter-balancing 137.9 N (31 lb) (one-sixth of the test subject's weight) placed on the foot board. The 137.9 N (31 lb) weight was removed and the pressure suited test subject balanced in the five-degree-of-freedom simulator. Evaluation exercises consisted of walking on the foot board, jumping, and attempting to manipulate space hand tools without the aid of tethers. The simulation of one-sixth earth gravity conditions appeared to be realistic with no major problems encountered. The five-degree-of-freedom simulator performed quite well under the reduced load of approximately 667.2 N (150 lb).

Recommendations

It is recommended that a simple, light platform be built to be used by the test subject while mounting and dis-mounting the simulator. At present it is necessary to use whatever is available to stand on for this operation, often sacrificing safety. The platform should be approximately 0.6 m (24 in.) high and 0.6 m (24 in.) square with a non-slip top.

The present bicycle seat should be replaced by a longer, slimmer model. The present seat is too wide to allow the test subject to utilize dutch shoes and move about in comfort. The recommended replacement seat is of the "English Racing" variety and should prove quite satisfactory.

The original rigid body cradle was secured when not in use in both the roll and pitch planes by two aluminum rods. The pitch rod will not connect to the bicycle seat unit until either the rod or the conversion unit is modified. The recommended modification is an 0.0064 m (0.25 in.) thick aluminum plate to be welded to the conversion unit in such a fashion that it will accept the 0.0064 m (0.25 in.) diameter restraint rod detent pin.

EVALUATION OF THE SIX-DEGREE-OF-FREEDOM SIMULATOR

Summary

A comparison of the existing simulator device against the "ideal" of a true zero-g space environment is presented. The forces and torques required as well as the degree and distance of movement allowed for the six-degree-of-freedom mechanical simulator were measured and are presented herein along with operating procedures, equipment size limitations and recommendations for future development. Results of this study were extracted from the Hayes International Corporation report SE-25-67.

Introduction

The man rated six-degree-of-freedom mechanical simulator was conceived and fabricated to study zero-g man/machine relationships in maintenance and fabrication techniques. These tests were conducted to re-establish the performance values of the simulator since its recent modifications.

Unfortunately no earth bound mechanical simulator, no matter how well designed, can completely duplicate the totally frictionless and weightless environment of space.

However, testing experience gained by utilizing even these less than ideal simulators is most valuable.

The six-degree-of-freedom zero gravity simulator shown in Figure 11 is constructed principally of aluminum and fiberglass. The supporting framework is 6.6 m (261 in.) wide and 4.9 m (192 in.) deep, the major height is 8.8 m (337 in.) and the height from the floor to the air bearing platform is 4.8 m (188 in.). This device allows a test subject a full six degrees of freedom: vertical, lateral, longitudinal, pitch, roll, and yaw. The vertical movement is made possible by constant force "negator" springs; the horizontal movement by air bearing pads; and the pitch, yaw, and roll movements by conventional bearings. Provisions have been made for counter balancing lower limb movements to maintain the subject' center-of-gravity. Breathing air is available for space suited subjects through utilization of rotary union couplings.

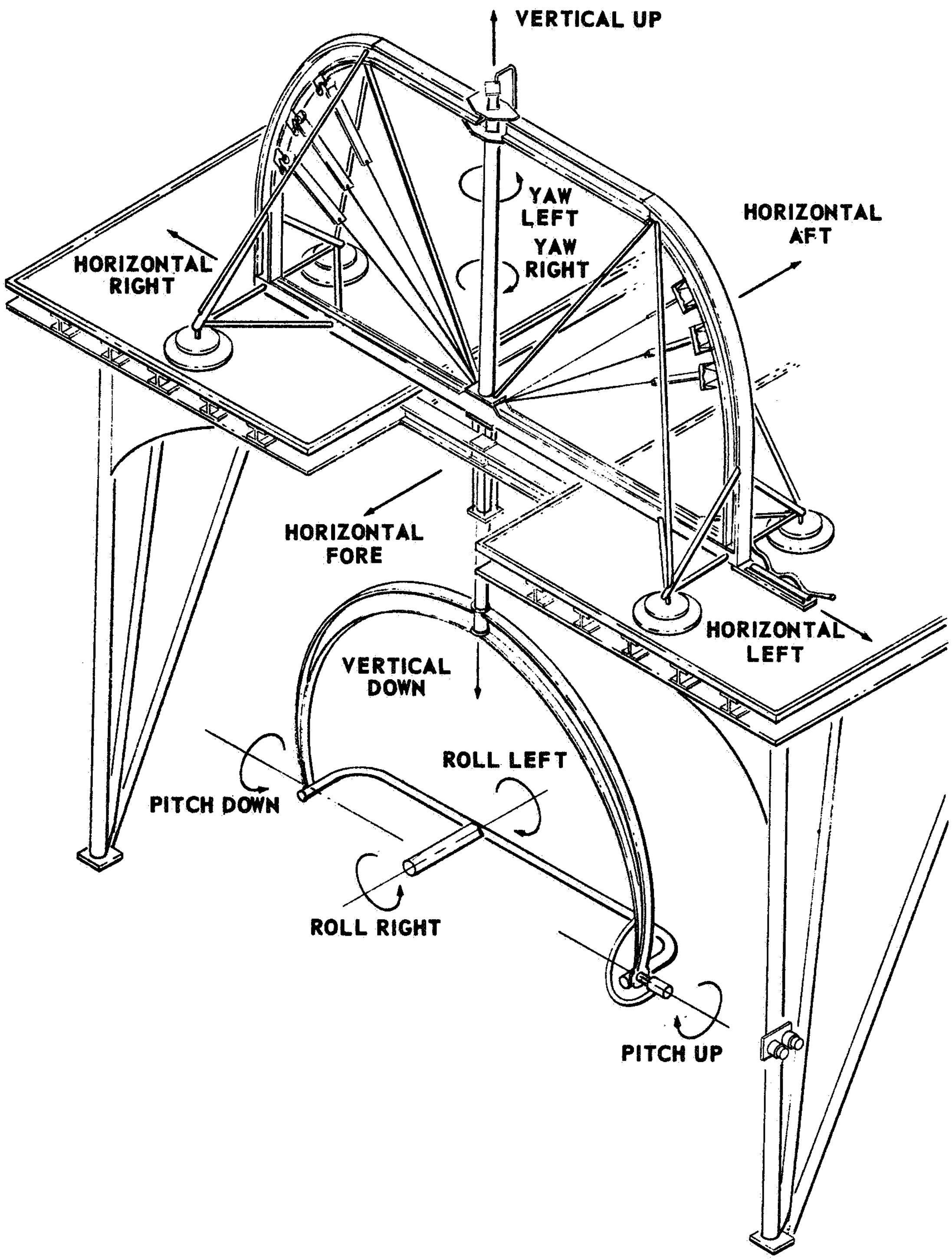

FIGURE 11. SIMULATOR AXES

The suspension system used in the six-degree-of-freedom simulator has been designed to minimize friction and counteract the effects of earth gravity as much as possible.

The test subject restraint harness and bracket assembly is attached to the suspension gimbals in a manner to insure occupant safety.

Certain combinations of 90-degree roll and pitch can cause the feet to strike the gimbals. If the feet are held straight out they will clear the gimbals.

The information compiled in Tables XV and XVI can be used as correction factors in the data analysis of simulator mounted experiments.

TABLE XV. DISTANCE OR DEGREE OF MOTION

Vertical	1.98 m (78 in.)
Horizontal (Fore/Aft)	3.3 m (131 in.)
Horizontal (Right/Left)	1.8 m (78 in.)
Roll	360 degrees
Pitch	360 degrees
Yaw	360 degrees

Experiment Size Limitations

The inside dimensions of the simulator are presented in the scaled drawing shown in Figure 12.

It should be noted that, with the harness in the lowest position, the test subject's shoulder is approximately 1.7 m (68 in.) from the ground, and his ground clearance is approximately 0.2 m (9 in.). These dimensions should be taken into account when designing work and access areas on experiments.

In addition, the size of the elevator giving access to the work area is 2.5 m (100 in.) in length by 2.3 m (91 in.) in width by 2.3 m (90 in.) in height with doors 2.1 m (84 in.) in width by 2.1 m (84 in.) in height and has a capacity of 35 585 N (8000 lb). All larger or heavier experiments must be brought in by crane, which is difficult because the crane does not extend over the work area.

TABLE XVI. FORCES AND TORQUES REQUIRED FOR MOTION

Vertical			
Near the top of travel:		Near the center of travel:	
up	44.5 N (10 lb)	up	35.6 N (8 lb)
down	40.0 N (9 lb)	down	53.4 N (12 lb)
Near the bottom of travel:			
up	35.6 N (8 lb)		
down	64.5 N (14.5 lb)		
	±2.2 N (±0.5 lb)		
Horizontal			
Near the top of vertical travel: (fore and aft)	1.9 N (7 oz)	Near the bottom of vertical travel: (fore and aft)	6.7 N (24 oz)
Near top and bottom of vertical travel: (right and left)	7.8 N (28 oz)		
Roll			
Subject flat on back:		Subject Erect:	
Right	0.21 m-N (30 in.- oz)	Right	0.78 m-N (113 in.-oz)
Left	0.74 m-N (105 in.-oz)	Left	1.23 m-N (180 in.-oz)
			0.14 m-N (20 in.-oz)
Pitch			
up	1.16 m-N (165 in.-oz)		
down	0.32 m-N (45 in.-oz)		
	0.12 m-N (20 in.oz)		
Yaw			
Right	0.32 m-N (45 in.-oz)		
Left	0.32 m-N (45 in.-oz)		
	0.07 m-N (10 in.-oz)		

NOTE: The articulated leg linkage and counterweights nearly maintain the subjects center of gravity. There are no counterweights for the arms. The arms should be held in the as-balanced position during tests on the simulator.

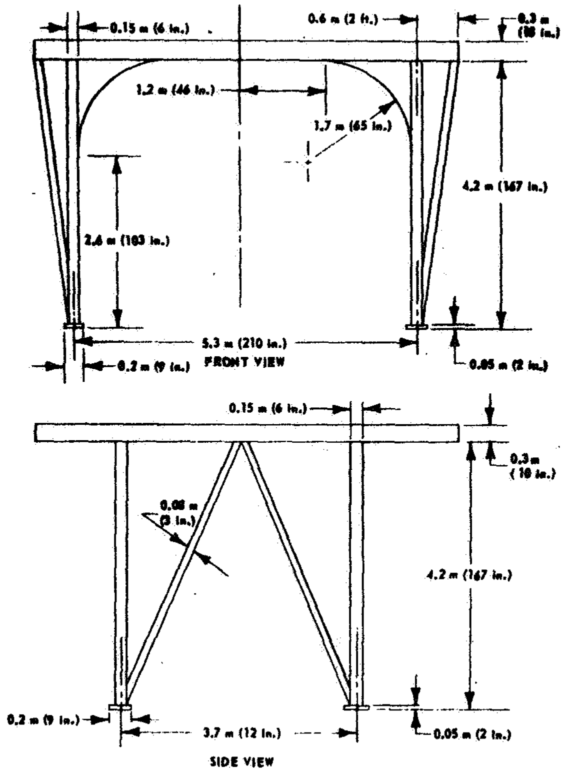

FIGURE 12. SIMULATOR EXPERIMENT CLEARANCES

Operating and Safety Procedures

The operating instructions[1] should be followed in detail and additional safety instructions are given below:

Loading and unloading the test subject — from the simulator can be hazardous. Insure that the simulator is tightly tied down and the foot stool is provided for the test subject prior to loading or unloading. In addition to the safety rope, at least two people must hold the simulator down to avoid injuring the test subject. Some of the harness edges are sharp and can cut clothing and space suits.

Note: Chest tiedown straps should be fastened first, then the leg tie downs fastened when putting the subject into the simulator.

Changing or adjusting the negator springs — should be accomplished with extreme caution because they are under considerable tension. In addition, care should be taken when working on the top surface because it is slippery. Do not walk on the finished surface with shoes. Insure that the ladder to the top of the platform is securely tied to the platform.

Test subject movement — should be performed without getting limbs caught between the yoke and the harness. Rapid motion could cause injury. Also, the simulator should not be driven hard against the stops, as one of the air pads could jump off the platform. The test subject should never be left unattended while in the simulator.

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[1]Tool Instructions, Action Reaction Free Fall Simulator MIT0357-14529, Manufacturing Engineering Laboratory, MSFC, 1 December 1966.

Conclusions

Movement of subjects' arms can change the subjects' center of gravity. This may be used to orient the subject if desired, but during tests the arms should be held as nearly as possible in the as balanced position.

When the back rest is adjusted toward maximum width, and the articulated leg mechanisms toward the minimum width these units then tend to bind and full articulated leg movement is not possible. This can be avoided by proper adjustment.

The counterweighted arm sections may catch on the rear of the yoke in certain positions. These are unusual combinations of position and are not normally incurred in operation of the simulator.

STORABLE TUBULAR EXTENDIBLE MEMBERS (STEM)

Introduction

Since 1960, DeHavilland's special products and applied research division has pioneered the design, development and manufacture of Storable Tubular Extendible Members (STEM) for space applications. Both self-extendible and motorized STEM devices have been successfully flown as antennas, instrument carrying booms, gravity gradient stabilization rods, and structural members.

The purpose of this engineering evaluation is to verify and develop the capabilities of the DeHavilland STEM Model A-32 for use as a tool handling device. Determination of the controllability of the tool handling claw is one of the prime objectives of this evaluation.

This section presents experiment procedures and results obtained during the evaluation of the DeHavilland STEM for use as a tool handling device as set forth in Technical Directive R-ME-MM-79, and reported in MEL Technical Report SE-35-67, Hayes International Corp.

Evaluation Hardware

STEM UNIT

The STEM (Fig. 13) is essentially a tape of thin material which assumes a tubular shape when extended. This tubular element consists of three furled, stainless steel element strips each nestled within the other to achieve maximum rigidity. The tape, when retracted, is stored in a strained and flattened condition by winding it onto a drum. As the circular element is retracted, it is smoothly transferred into a flattened strip by passing it through a guidance system. Fully extended, this tubular element is approximately 4.75 m (187 in.) long. The outside diameter of the tubular element when extended is 0.02 m (0.9 in.). It is extended and retracted by a 28 Vdc motor (2.5 amperes) located inside the STEM package.

CLAW DEVICE

This device (Figs. 13 and 14) was designed as an electro-mechanical aid for evaluating the STEM. It consists of a 28 Vdc pull-type relay, simple

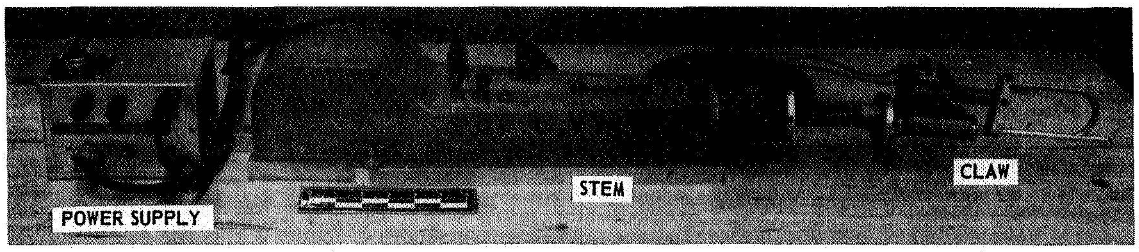

FIGURE 13. STORABLE TUBULAR EXTENDIBLE MEMBER (STEM) UNIT

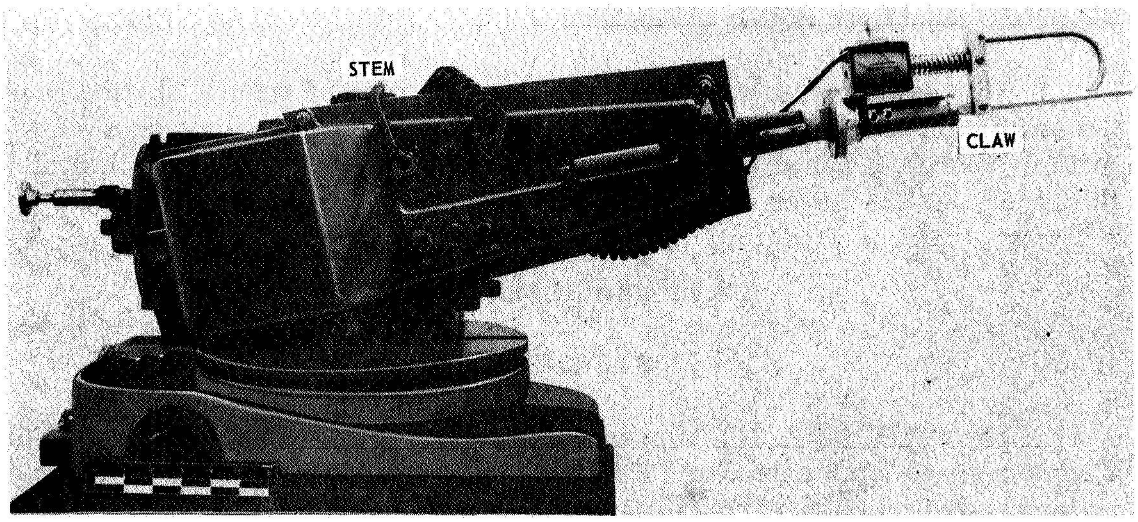

FIGURE 14. STEM AND CLAW DEVICE

linkage, and a fabricated claw of aluminum tubing. When the operating button is depressed, the 28-volt relay is energized and opens the normally closed claw. It will remain open as long as the button remains depressed.

AIR BEARING CART

The air bearing cart is a general purpose platform developed to provide a means of evaluating space oriented devices. The platform consists of an electric blower that supplies lift air to four pads mounted beneath the platform (Figs. 14, 15, and 16).

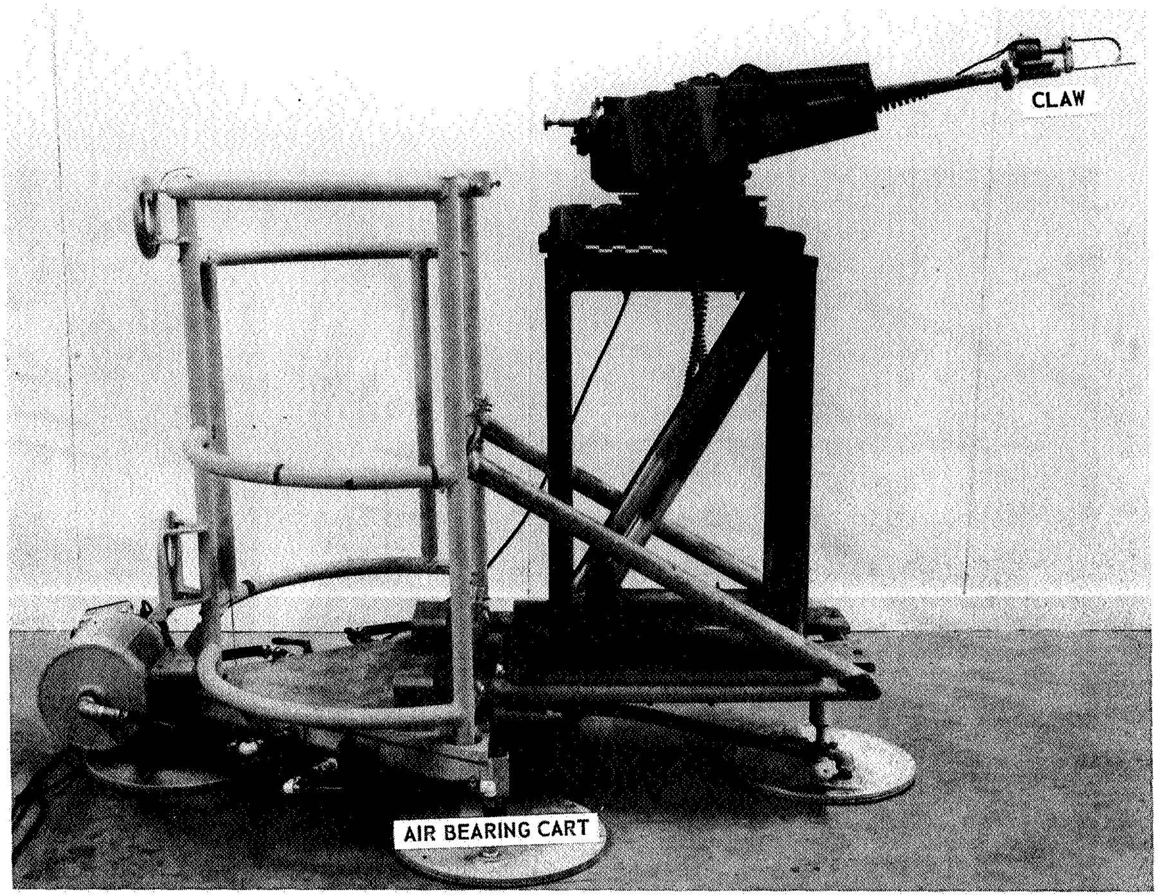

FIGURE 15. STEM MOUNTED ON AIR BEARING CART

MARTIN FIVE-DEGREE-OF-FREEDOM MECHANICAL SIMULATOR

This unit (Figs. 17, 18, and 19) is an air bearing device designed primarily for zero gravity simulation. It permits low friction motion by a test subject in all planes and axes except vertical.

SPACE TOOLS

The following full-scale models of zero reaction space tools were used in the evaluation:

1. Craftsman Push-Release Ratchet
2. Modified "Yankee" Screwdriver
3. T-Handle Gauntlet
4. Inertia Wheel Tool
5. Space Impact Wrench

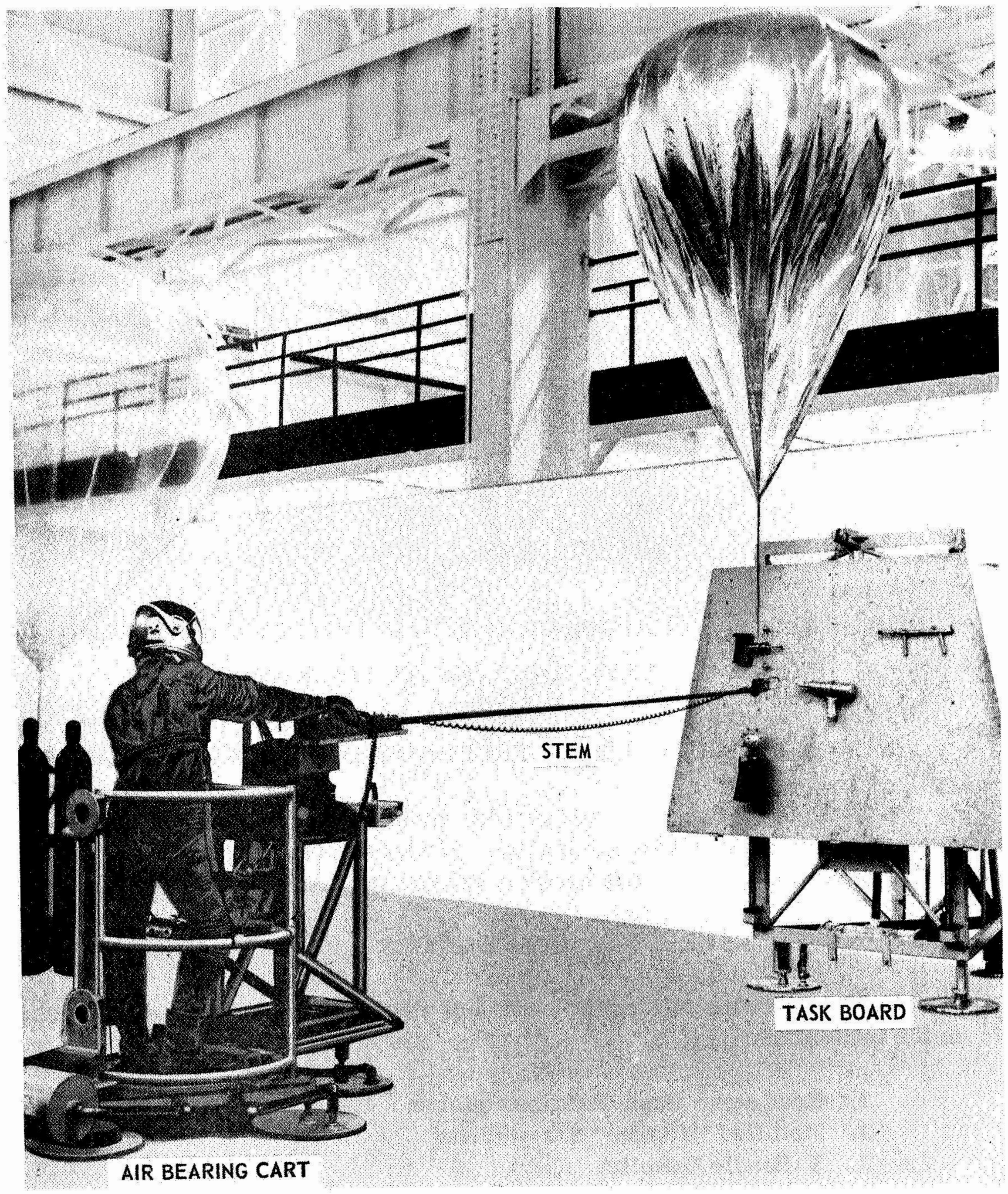

FIGURE 16. AIR BEARING CART/STEM EVALUATION

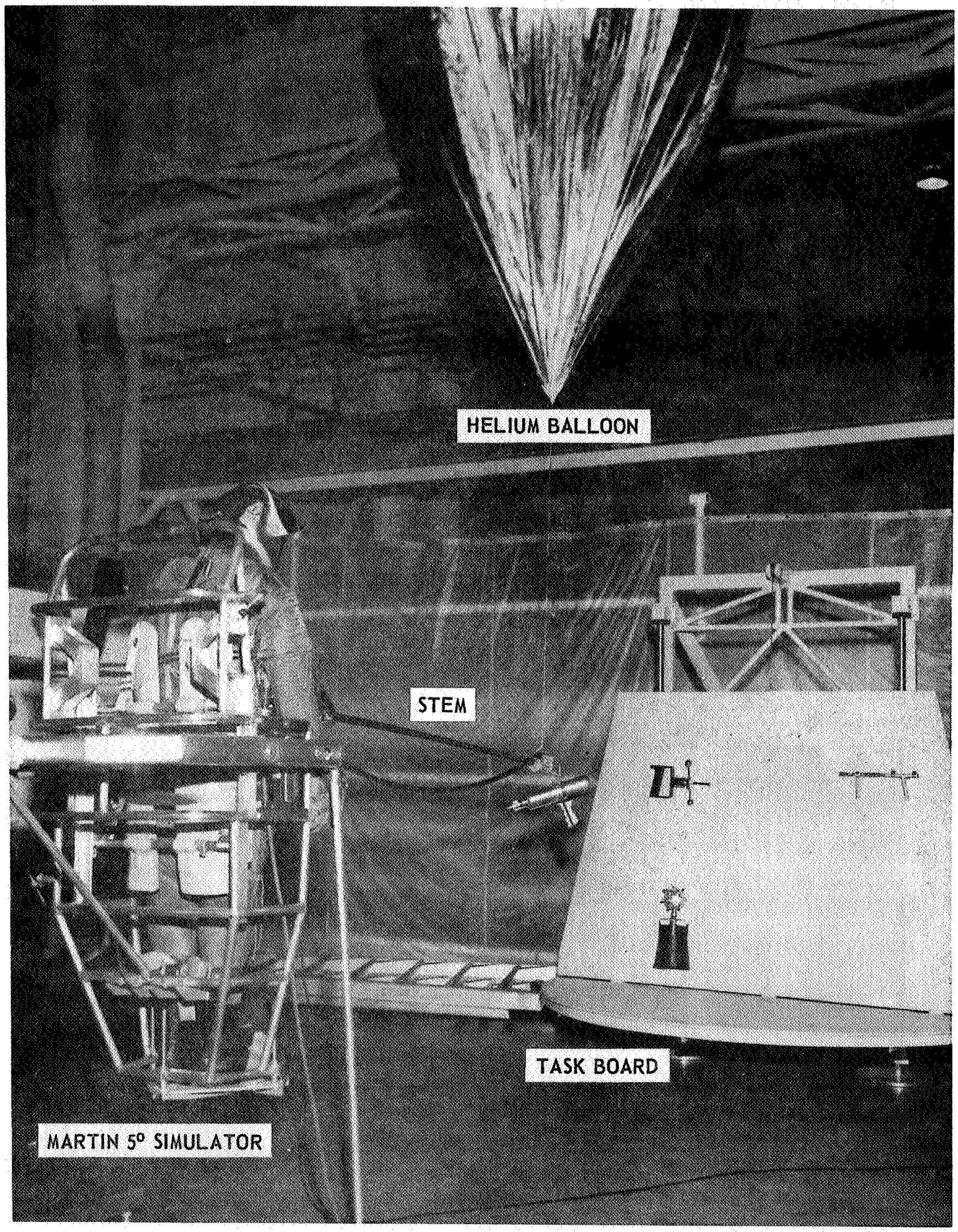

FIGURE 17. FIVE-DEGREE-OF-FREEDOM SIMULATOR/STEM EVALUATION

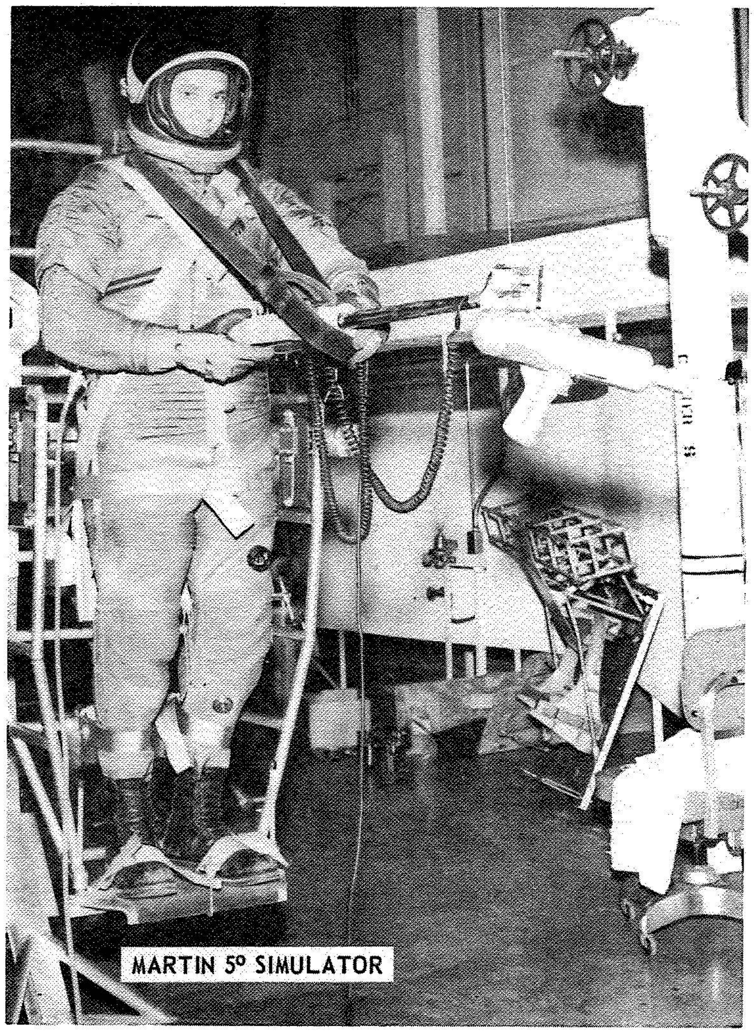

FIGURE 18. FIVE-DEGREE-OF-FREEDOM SIMULATOR/STEM EVALUATION

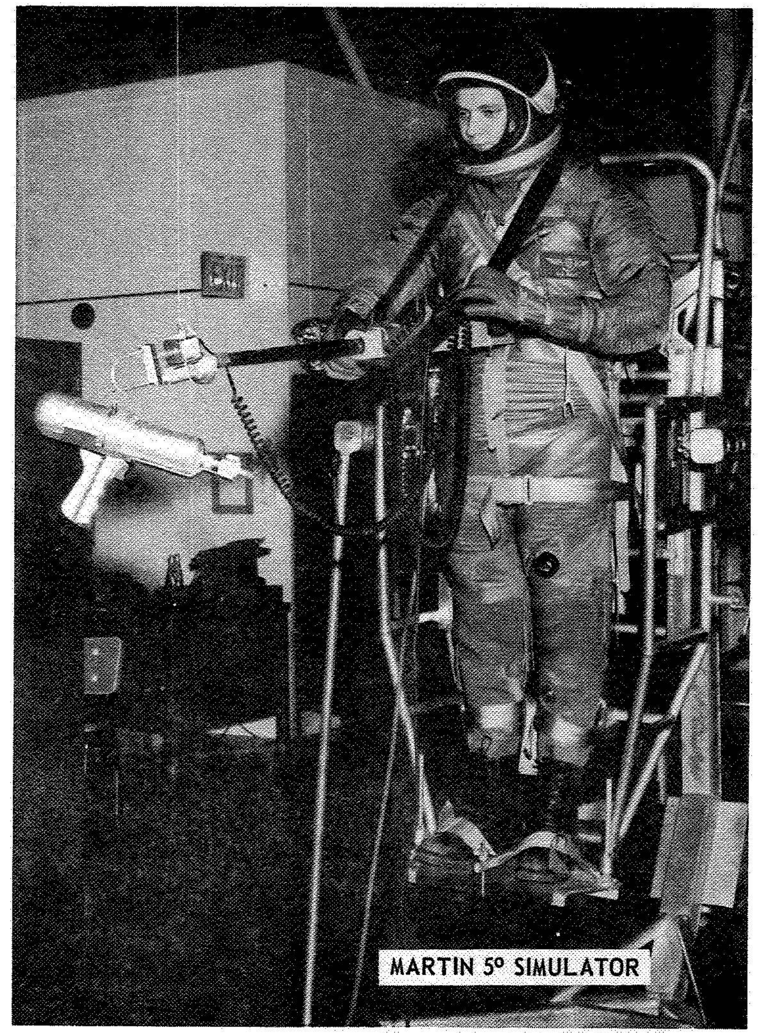

FIGURE 19. FIVE-DEGREE-OF-FREEDOM SIMULATOR/STEM EVALUATION

Evaluation Procedure

The Engineering Test Plan for the development and evaluation of the DeHavilland STEM is presented in Appendix A.

TEST SET UP AND EVALUATION

The STEM evaluation was conducted while being supported on the Martin five-degree-of-freedom mechanical simulator and an air bearing cart. The results of the two evaluations follow:

Martin Five-Degree-of-Freedom Simulator. An attempt was made to evaluate the STEM using the Martin five-degree-of-freedom mechanical simulator to support the STEM unit. The full torso support basket was used to support the test subject. The STEM unit with roll and pitch was locked out due to binding of the STEM when rotated more than 45 degrees from the vertical. The STEM unit was hand held by the subject.

The test subject was suited in a Navy Mark IV full pressure suit and secured in the torso support basket by means of foot, leg, waist, and shoulder harness. To assist the subject, restraint straps were placed under the STEM package and around the subject's neck to provide additional STEM support in the fully extended position. A helium filled balloon, as shown in Figure 17, was fastened to the claw device to support the STEM when fully extended. This was necessary to prevent the extended STEM from twisting due to lack of torsional rigidity.

Air Bearing Cart. The air bearing cart was used as a fixed platform to support the STEM unit and was not under evaluation. The cart was used in conjunction with a gimbal attached to the STEM mounting bracket. In this position the subject was able to manipulate the STEM to extend, grasp a tool, and retrieve it. The evaluation procedure was the same as that for the Martin five-degree-of-freedom-mechanical simulator. Five series of three attempts to retrieve each tool mounted to the task board were performed.

In this experiment the rate of extension was calculated to be 0.3 m/sec (12 in./sec) while the retraction rate was 0.15 m/sec (6 in./sec).

Results

Complete failure was experienced when attempts were made to operate the device for evaluation.

It was first noted that the extended boom lacked the torsional rigidity required to extend and retrieve objects. Also noted was the absence of strength in the three nestled elements comprising the STEM Model A-32.

Repeated mechanical and electrical malfunctions were encountered with the drive mechanism, resulting in delay.

Because of these failures, the original engineering plan was altered to the present concept.

PROBLEMS ENCOUNTERED

During this evaluation these failures were experienced and the following corrective action resulted:

Failure to Retract or Extend.

Cause of Failure. Investigation revealed the 28 Vdc motor clutch type brake was binding the motor shaft inducing an overheating condition.

Correction. The 28 Vdc motor assembly was disassembled, checked, and reassembled with extreme care exercised in alignment of the motor assembly. This condition occurred several times and was finally corrected by carefully shimming the motor housing to insure the motor shaft was free running when the motor was assembled and housing bolts were secured.

28 Vdc Motor Failure.

Cause of Failure. A motor bearing burned out due to overload. The one-sixth duty motor apparently was not adequate for continuous operation. This unit was an "off the shelf" item primarily designed as an antenna motor for limited usage.

Failure to Support Weight When Fully Extended – 4.75 m (187 in.).

Cause of Failure. This unit contained a STEM made of three elements 0.1m (4 in.) by 0.0013 m (0.005 in.) nestled within each other for added rigidity. However, the rigidity was found to be inadequate to support the test loads of 0.91 kg (2 lb) or more resulting in excessive droop.

Correction. In order to execute this evaluation plan, it was necessary to support the weight of the STEM (claw end) by means of a helium filled balloon to overcome the weight of the extended STEM, the claw device, and the test load.

The following droop data was compiled after extending the tubular member to its limit of horizontal travel. Thus it was possible to measure at 0.31 m (1 ft) intervals the amount of droop in meters (inches).

TABLE XVII. STEM EXTENSION VERSUS DROOP

Extension m (ft)	Droop m (in.)
0.31 (1.0)	(0.0)
0.61 (2.0)	(0.0)
0.91 (3.0)	0.013 (0.5)
1.22 (4.0)	0.025 (1.0)
1.52 (5.0)	0.033 (1.3)
1.83 (6.0)	0.064 (2.5)
2.13 (7.0)	0.083 (3.25)
2.44 (8.0)	0.114 (4.5)
2.74 (9.0)	0.152 (6.0)
3.05 (10.0)	0.197 (7.75)
3.35 (11.0)	0.260 (10.25)
3.66 (12.0)	0.330 (13.0)
3.96 (13.0)	0.400 (15.75)
4.27 (14.0)	0.470 (18.5)
4.57 (15.0)	0.559 (22.0)
4.80 (15.75)	0.648 (25.5)

Conclusions

Despite the limitations of the DeHavilland STEM Model A-32, the present concept is basically sound. In any future study of the present design concept, the items outlined in Recommendations should be taken under consideration. In order to evaluate zero-g operation while operating in one-g environment, a study of key modifications that might be incorporated into the present STEM package should be initiated.

Recommendations

DeHavilland Aircraft of Canada has recently announced the availability of two off-the-shelf units designed primarily for ground application and directed toward tool handling applications. These two concepts are described as being 0.035 m (1.38 in.) diameter STEM, capable of hoisting a 4.54 kg (10 lb) tip load out to 7.62 m (25 ft), and a 0.089 m (3.5 in.) diameter STEM capable of hoisting a 34.02 kg (75 lb) tip load.

In view of the principle findings concerning the present design concept and supported by the knowledge that there exists two STEM models designed specifically for ground support, it is recommended that a study be made of these two new design concepts for any future evaluations made in this area. Other recommended investigations include:

1. Lighter weight of STEM package
2. Smaller physical dimensions of STEM package
3. Increased torsional rigidity
4. Design simplicity
5. Internal electrical lines
6. Use of non-corrosive material (for neutral buoyancy studies)
7. Increased positive response on extension and retraction
8. Combine control switches into one control similar to an aircraft joy-stick
9. Accelerate the rate of extension and retraction

THRUSTER ASSEMBLY

Summary

Evaluation tests were performed on a thruster assembly, mounted on an air bearing test cart (Fig. 20), to determine such capabilities as maximum thrust, acceleration, and velocity. Thrusters of identical type will be used on a special air bearing test cart for evaluating a master-slave grappler arm device.

The work was accomplished under Technical Directive R-ME-MM-15 and reported in MEL Technical Report SE-33-67, Hayes International Corp.

Thruster System Description

The thruster assembly (Fig. 21) consists of a spherical air tank approximately 0.61 m (2 ft) in diameter, an air regulator with output range from 0 to 1 896 058 N/m^2 (0 to 275 psi), a 110 Vac powered solenoid for on-off air control, and a small thruster nozzle shown in Figure 22. The spherical air storage tank is provided with a fill valve and may be filled from portable high pressure air storage tanks or a high pressure air line.

Evaluation Procedure

Appendix B consists of a proposed test plan for the thruster assembly. The purpose of this test is to determine the capabilities and the general characteristics of this assembly, rather than any detailed specifications.

Thrust Characteristics

MASS DETERMINATION

The mass of the test cart and thruster was determined by weighing the entire assembly on a large platform scale and dividing the assembly weight (Newtons [pounds]) by the gravitational acceleration (meters/second^2 [feet/second^2]). The calculation and result are shown below.

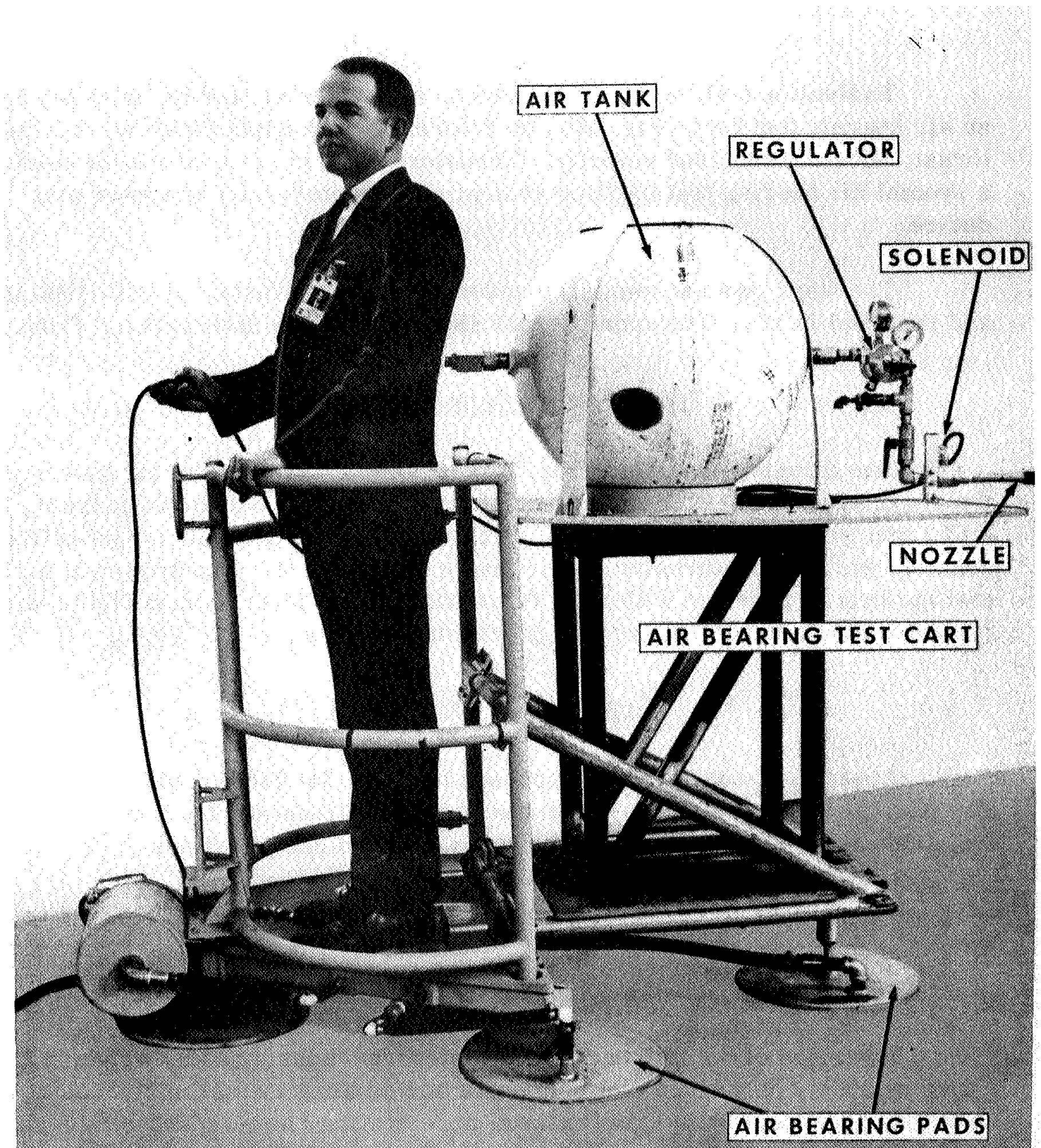

FIGURE 20. THRUSTER ASSEMBLY MOUNTED ON AIR BEARING TEST CART

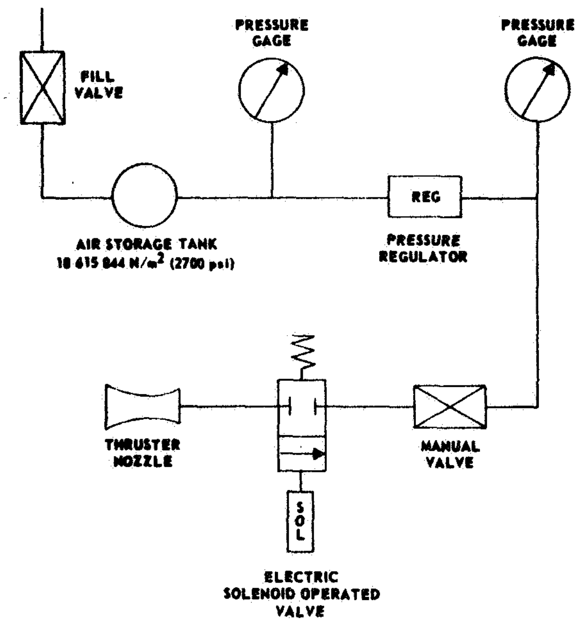

FIGURE 21. THRUSTER ASSEMBLY PNEUMATIC SCHEMATIC

$$\text{Mass} = \frac{\text{weight of assembly}}{\text{gravitational acceleration}}$$

$$= \frac{156.94 \text{ kg } (346 \text{ lb})}{9.75 \text{ m/sec}^2 \ (32 \text{ ft/sec}^2}$$

$$= 157.62 \text{ kg } (10.8 \text{ slugs}) \ .$$

BEARING DRAG

With the air bearings operating, a small spring scale rated 0 to 44.48 N (0 to 10 lb) was attached to the cart and the force required to set it in forward motion was read from the scale. The bearing drag was determined to be approximately 7.78 N (1.75 lb).

MAXIMUM STATIONARY THRUST

One end of a spring scale rated 0 to 133.45 N (0 to 30 lb) was attached to the nozzle end of the assembly and the other end attached to a stationary object. With no slack in the tie string, to avoid measuring force due to impact, the thrustor was activated and the force read from the scale. With nozzle pressure regulated at the maximum possible value of 1 896 058 N (275 psi), the maximum thrust was determined to be approximately 60.05 N (13.5 lb).

MAXIMUM ACCELERATION

Times were measured for the thruster and cart to start from rest and travel distances of 3.05 m, 4.57 m, and 6.10 m (10 ft, 15 ft, and 20 ft) with nozzle pressure regulated at 1 896 058 N/m^2 (275 psi). When the nozzle valve was activated, the regulated pressure dropped to approximately 689 475 N/m^2 (100 psi) and remained constant at this value. This gage is designed and mounted for static pressure measurement; therefore, it does not give a true reading of the actual downstream pressure when the nozzle valve is "on." Under the assumption that acceleration should be nearly constant for a short distance, the following formula was used:

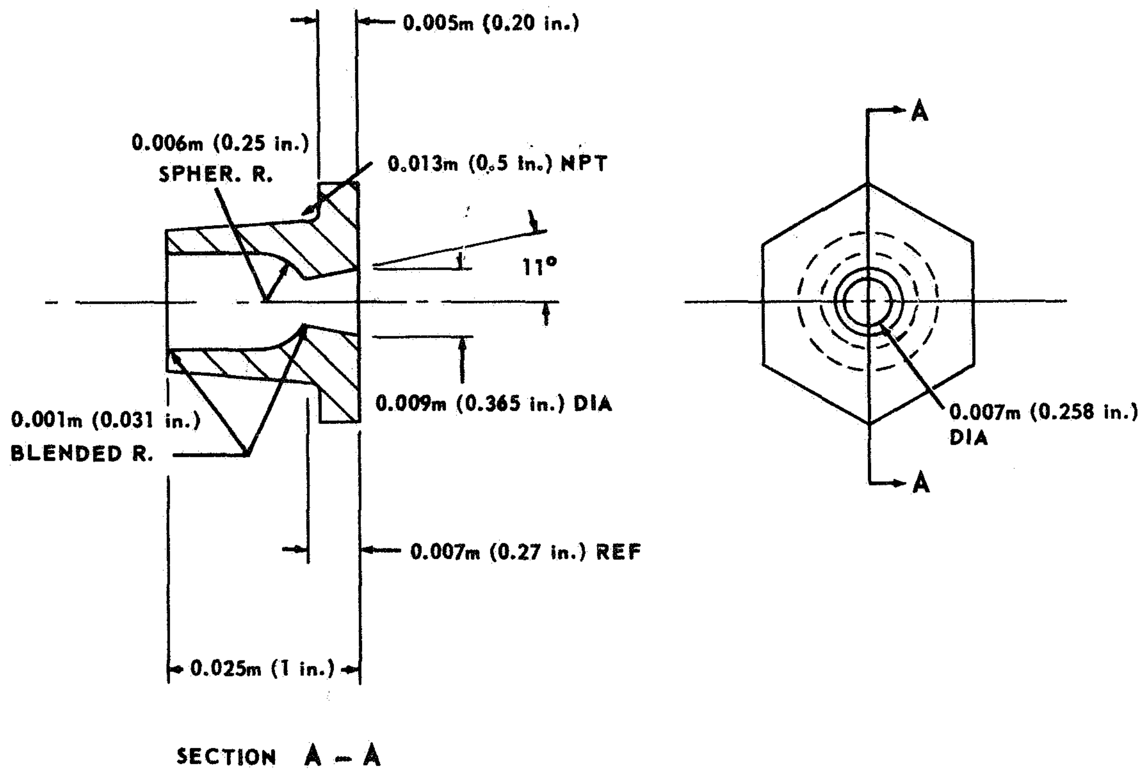

FIGURE 22. THRUSTER NOZZLE

$$\text{Acceleration} = \frac{2(\text{distance traversed})}{(\text{total elapsed time})^2}$$

thus, values of acceleration determined were as follows:

3.05-m (10-ft) run: a = 0.209 m/sec^2 (0.685 ft/sec^2)

4.57-m (15-ft) run: a = 0.198 m/sec^2 (0.650 ft/sec^2)

6.10-m (20-ft) run: a = 0.190 m/sec^2 (0.625 ft/sec^2)

MAXIMUM VELOCITY

Velocity of the cart and thruster was determined by activating the thruster a considerable distance from a marked 3.05 m (10-ft) interval and measuring the time required to cross it. Runs were made starting from approximately 10.67 m (35 ft) and 15.24 m (50 ft) from the marked interval, and the respective average velocities across it were 1.8 m/sec^2 (5.9 ft/sec^2) and 2.16 m/sec^2 (7.1 ft/sec^2).

PROPELLANT (AIR) CONSUMPTION RATE

With the nozzle pressure regulated at the maximum value of 1 896 058 N/m^2 (275 psig), the thruster was activated and the time required for the tank pressure to decrease from 3 654 221 to 2 964 745 N/m^2 (530 to 430 psig) was 13.4 seconds. With a maximum rated working pressure 16 547 417 N/m^2 (2700 psig), the available operating time at full nozzle pressure was calculated as shown below:

Let X = amount air (m^3 [ft^3]) in the tank at 16 547 417 N/m^2 (2700 psig)

$$\text{At } 3\ 654\ 221 \text{ N/m}^2 \text{ (530 psig)}: \text{amount of air} = \frac{3\ 755\ 574 \text{ N/m}^2 \text{ (544.7 psia)}}{18\ 717\ 197 \text{ N/m}^2 \text{ (2714 psia)}}$$

$$\therefore x = 1385.9 \text{ N/m}^2 \text{ (0.201 psia)}$$

$$\text{At } 2\ 964\ 745 \text{ N/m}^2 \text{ (430 psig)}: \text{amount of air} = \frac{3\ 066\ 098 \text{ N/m}^2 \text{ (444.7 psia)}}{18\ 717\ 197 \text{ N/m}^2 \text{ (2714 psia)}}$$

$$\therefore x = 1130.7 \text{ N/m}^2 \text{ (0.164 psia)}$$

$$\text{Amount of air used} = 1385.9 \text{ N/m}^2 \text{ (0.201 psia)} - 1130.7 \text{ N/m}^2 \text{ (0.164 psia)}$$

$$= 255.2 \text{ N/m}^2 \text{ (0.037 psia)}$$

Amount of air not usable at maximum nozzle pressure of 1 896 058 N/m^2 (275 psig) is

$$x = \frac{1\ 997\ 411 \text{ N/m}^2 \text{ (289.7 psia)}}{18\ 717\ 196 \text{ N/m}^2 \text{ (2714.7 psia)}} = 758.4 \text{ N/m}^2 \text{ (0.11 psia)}$$

$$\text{Usable air} = 758.4 \text{ N/m}^2 \text{ (0.11 psia)} = 6136.3 \text{ N/m}^2 \text{ (0.89 psia)}$$

$$\text{Available time} = 6136.3 \text{ N/m}^2 \text{ (0.89 psia)} \left(\frac{13.4 \text{ seconds}}{225.2 \text{ N/m}^2 \text{ (0.037 psia)}} \right)$$

$$= 322 \text{ seconds}$$

Coast Characteristics

In addition to the tests proposed in the test plan (MEL Technical Report SE-29-67, Appendix B), a test was performed to determine the approximate coasting distance of the assembly for a nozzle burst of a given time duration. For nozzle bursts of two seconds and three seconds the coasting distances, measured from the point where the burst was applied, with the cart at rest and nozzle pressure at 1 896 058 N/m^2 (275 psi), were approximately 3.05 m (10 ft) and 4.57 m (15 ft) respectively.

Each of the tests performed is discussed with comments on some of the factors which could have affected the results obtained.

MASS DETERMINATION

The determination of mass was made with the air tank empty; therefore, the mass would be somewhat greater with air in the tank. The mass of air contained in the tank will be dependent upon both temperature and pressure. Temperature variance should be slight under indoor test conditions. The mass of air in the tank will vary almost directly with the pressure. When filled to capacity, the mass of air in the tank is only a fraction of the mass of the assembly and would have almost negligible effect on performance.

BEARING DRAG

Measurements of bearing drag varied at different points on the floor, but the value at most places checked was approximately 7.78 N (1.75 lb).

MAXIMUM STATIONARY THRUST

In this test, the cart moved while extending the scale, which probably caused the reading to be a little higher than the effective value. This was caused by a slight impact and a decrease in effective bearing drag.

MAXIMUM ACCELERATION

The values of acceleration decreased with each increase in test distance indicating the acceleration was not constant. However, this decrease was so small that the assumption of constant acceleration for the first 3.05 m (10 ft) should result in a very close approximation of the true maximum acceleration.

Theoretically, the acceleration may be calculated from mass, thrusting force, and bearing drag as follows:

$$\text{Acceleration} = \frac{\text{thrusting force - bearing drag}}{\text{mass}}$$

$$= \frac{60.05\ \text{N}\,(13.5\ \text{lb}) - 7.78\ \text{N}\,(1.75\ \text{lb})}{157.62\ \text{kg}\,(10.8\ \text{slugs})} = 0.33\ \text{m/sec}^2\ (1.08\ \text{ft/sec}^2)$$

The fact that the theoretical value of acceleration is somewhat higher than the experimental value is probably caused by a high value of thrust (see Maximum Stationary Thrust) and to variations in bearing drag caused by an uneven test surface.

MAXIMUM VELOCITY

From the difference in the values of velocity for the two runs, it was apparent that the assembly was still accelerating between 10.67 m (35 ft) and 15.24 m (50 ft). Although the acceleration had appreciably decreased, it is probable that some acceleration would continue to take place for a distance much greater than 15.24 m (50 ft). Longer trail runs were not practical because of lack of floor space and the difficulty in keeping the assembly traveling in a straight line for such distances.

PROPELLANT (AIR) CONSUMPTION RATE

The test on propellant consumption began with the air tank at an ambient temperature of approximately 298°K (80°F); however, the expending gas caused some cooling. If the thruster nozzle were left on continuously while a full tank of air was expelled, the reduction in pressure due to cooling might significantly affect the available operating time. However, under normal operation, the nozzle will only be activated intermittently and the pressure reduction due to expansion cooling would be slight.

COASTING DISTANCE

For nozzle bursts of a few seconds, the ratio of coast to thrust distance would probably remain close to the experimental value of 1.52 m/sec (5 ft/sec) of nozzle burst. However, if the nozzle were left on long enough for the acceleration to decrease significantly, this ratio would decrease.

Conclusions

Although no tests were performed to evaluate the efficiency of the thruster nozzle, this factor could have been evaluated by comparing the measured thrust of 60. 05 N (13. 5 lb) with the maximum possible thrust obtainable with an ideal nozzle. In order to determine the maximum theoretical thrust, it would be necessary to find the true value of the nozzle inlet pressure under dynamic conditions. This could be done by using two pressure gages, with the inlet of one mounted perpendicular to the direction of air flow (as the one on the thruster is mounted) and with the other mounted parallel to the flow direction. With these two readings, the optimum thrust could be calculated from equations of propulsion physics.

The following test data were obtained from the evaluation.

TEST DATA

Bearing Drag (approximate) .... 7. 78 N (1. 75 lb)

Maximum Stationary Thrust .... 60. 05 N (13. 5 lb)
(pressure regulated to 1 896 058. 23 N/m^2 (275 psi)

Acceleration .... 0 to 3. 05 m (0 to 10 ft) 5. 4 seconds

.... 0 to 4. 6 m (0 to 15 ft) 6. 8 seconds

.... 0 to 6. 1 m (0 to 20 ft) 8. 0 seconds

Coasting Distance .... 2 second burst, 3. 05 m (10 ft)

.... 3 second burst, 4. 6 m (15 ft)

Propellant Consumption ...... decreased from 3 654 222. 8 N/m^2 (530 psig) to 2 964 746 N/m^2 (430 psig) in 13. 4 seconds

Velocity .... 3. 05 m (10 ft) in 1. 7 seconds with 10. 7 m (35 ft) acceleration distance

.... 3. 05 m (10 ft) in 1. 4 seconds with 15. 2 m (50 ft) acceleration distance

Weight (propellant tank empty) ...... 156. 9 kg (346 lb)

PRE-DETERMINED DATA

Propellant tank working pressure	18 615 844.4 N/m^2 (2700 psi)
Propellant tank proof pressure	27 579 028.9 N/m^2 (4000 psi)

AIR BEARING PLATFORM

Introduction

This lightweight adjustable air bearing platform and support was designed and fabricated by the Space Maneuvering Devices group of the Space Division of North American Rockwell Corporation, Downey, California, in support of NASA Contract NAS8-20855.

The T50-2 air bearing platform was designed to provide stable based, near-frictionless simulation, by means of air pads operating on a smooth level floor. It is to be used in conjunction with the NASA serpentuator or other manual propulsion operations. The T50-2 has capability and versatility of being utilized in the studies and evaluations of docking, undocking, and other difficult simulated space maneuvers.

Performance Characteristics

SYSTEM DESCRIPTION

The T50-2 air bearing platform supports a nominal 90.72 kg (200 lb) load on an equilateral 0.91-m (3-ft) triangular base constructed of aluminum tubing. The two configurations are the manned version including a man-seat pedestal and serpentuator attach bracket, and the unmanned version which includes only the serpentuator support bracket (Fig. 23). The T50-2 base consists of a motor-blower combination, 3 air pads, an electrical control box, operator's control treadle switch, operator's motor speed control, and a 115 Vac 60 cycle unbilical recoiling power cord with connector.

The platform flotation lifting height can be adjusted with the speed control of the blower-motor. The platform levelness is controlled by manually adjustable valves which restrict the air flow delivery to each air pad thereby compensating for unbalanced loads.

Technical work performed during this contract is outlined in the technical proposal submitted to MSFC (SID 67-601-1) for the design of Air Bearing Platforms. During the contract negotiations, the following fixed technical requirements were established:

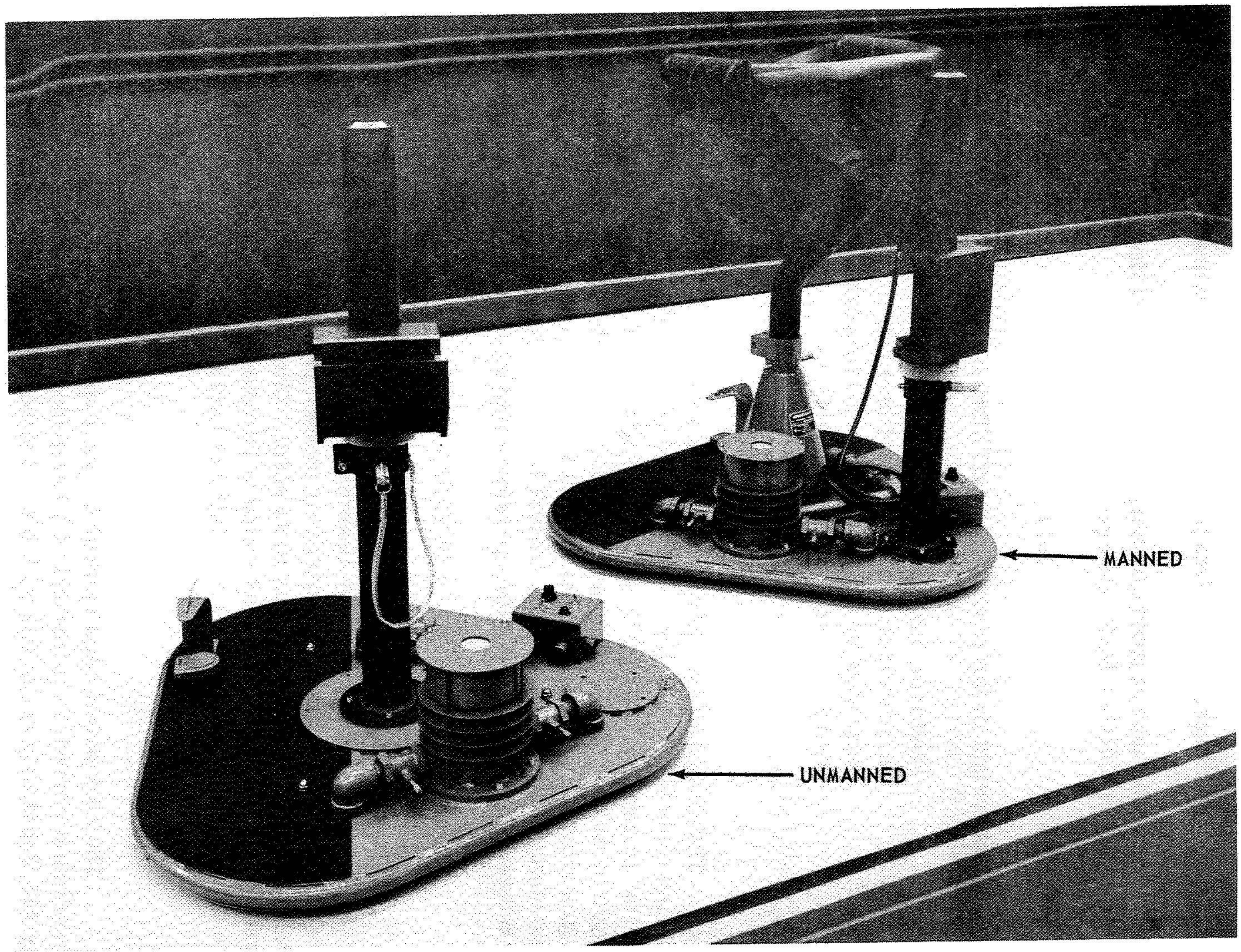

FIGURE 23. AIR BEARING PLATFORMS (T50-2)

1. The unit was to be powered by a 110 Vac single-phase, 60 cycle motor.

2. Air bags, rather than precision air pads were to be used.

3. The man support and serpentuator support details were to conform to established NASA designs.

MECHANICAL

The weight of the mechanical assemblies are:

Platform, air bearing T50-2	24.95 kg (55 lb)
Serpentuator attach post and bracket	5.44 kg (12 lb)
Serpentuator support, post, and bracket	5.44 kg (12 lb)
Operator's mast and safety yoke	8.16 kg (18 lb)

ELECTRICAL

The design of the electrical system provides for either continuous unmanned control or operator's continuous control of the platform flotation. The blower-motor is protected by a 10 ampere, combination circuit-breaker/toggle switch assembly. Manned or unmanned mode is controlled by a toggle switch mounted in the electrical control box. The unmanned speed control is also contained in the electrical control box. The manned platform is controlled by a treadle foot switch and the operator's blower-motor speed controller.

PNEUMATIC

The system contains 115 Vac to cycle blower, a distribution plenum chamber, three in-line air flow restrictor valves, and three air pads. The electric blower is capable of supplying plenum pressure of 17 216.9 N/m^2 (2.5 psig) up to flow deliveries of 15 scfm. (Refer to Appendix C, Engineering Evaluation: Blower Motor Performance Parameters.) The three aid pads are capable of floating a total air platform load in excess of 272.2 kg (600 lb).

POWER

The only power requirement is single-phase, 115 Vac, 60 cycle with a maximum current requirement of 10 amperes. This can be supplied from any 115 Vac utility outlet box with a third wire safety ground pin. The safety ground, if not available at a standard wall outlet, may be provided through the use of a parallel ground adapter, which adapts the 3-prong ac plug for use in standard 2-prong ac outlets. If the adaptor is used, the lead wire must be connected to a suitable electrical safety ground point.

Conclusions and Recommendations

The final design requirements, negotiated during the contract, included provisions for air flow control other than by throttling the air supply to the air pads. Technical data received from the supplier indicated that the pads could support light weight as well as heavy loads, but that variable input air pressures were required if light weight loads were not to create an instability. The commercially available pads are made more tolerant of weight extremes by means of enlarging the air port to the pad. The net effect is to drop the total lifting capability by about 30 percent; however, this reduces the lightest load that the pads can support by more than 50 percent.

At the request of NASA, a simulation of blower motor and air pad was provided along with a means for varying speed control. It was determined that voltage control of the motor is an ideal way of controlling air flow; motor heat is proportional to I^2R losses; pressure increases roughly squared with motor speed. Thus reduced pressure directly offsets motor heat rise. With less heat being generated, less cooling air is required.

The laboratory test results are presented in Appendix C. The work performed under the contract on motor speed control for air pressure variation was reported to the NASA Technology Utilization Group, and is presented in Appendix D.

The manned pedestal was loaded with 68.04 kg (150 lb), 22.68 kg (50 lb) over each aid pad. A tip-over torque was then applied to the serpentuator attach bracket to determine whether there were any unforeseen tip-over problems. The unit showed no rise from the floor until a torque of 16.27 N-m (12 ft-lb) was applied.

All design improvements were incorporated within the two units, prior to shipment. These design changes were evaluated and accepted during the design and development period of the contract. The Proof Procedure (acceptance test) for the air bearing platform is contained in Appendix E and the Acceptance Test Procedure is presented in Appendix F.

"INSERP" SERPENTUATOR

Summary

This section contains the results of mechanical zero-gravity simulation testing conducted with the electro-hydraulic "Inserp" serpentuator, and includes recommendations for the most efficient operating methods of the device and for possible design improvements. The work described herein was performed under Technical Directive R-ME-M-27 issued by the Manufacturing Engineering Laboratory, Marshall Space Flight Center, Huntsville, Alabama.

Serpentuator and Support Equipment Description

The serpentuator being operated by a pressure-suited test subject in the five-degree-of-freedom simulator is shown in Figure 24. This figure shows the device in base mode operation, in which its overall length is 4.74 m (186.25 in.). In tip mode operation the length is 1.81 m (71 in.). These measurements include the distance from the center of the actuator shaft to the mounting base. The major components of the serpentuator include a hydraulic fluid accumulator pressurized by argon gas at 340 000 N/m^2 (50 psi), a hand operated hydraulic pump, a hand operated control valve, an electric solenoid operated fluid cut-off valve, and a hydraulic actuator to convert fluid pressure produced at the pump to mechanical force on the tube. The end of the tube is supported by an air bearing platform which enables it to move under near frictionless conditions parallel to the plane on the floor. Although the tests are based on a 1.395-radian (80-degree) swing of the tube, the approximate freedom of movement is 3.14 radians (180 degrees).

The five-degree-of-freedom zero gravity simulator allows a test subject to move forward, reverse, left, and right, with yaw, pitch and roll capabilities. The test subject's freedom of movement is limited in pitch to approximately 0.872 radian (50 degrees) in each direction from vertical. Movements in the other directions are limited only by the simulation area. An adjustment mechanism is provided to make the test subject's center of gravity coincide with the simulator axes of rotation, thus simulating earth orbital weightlessness.

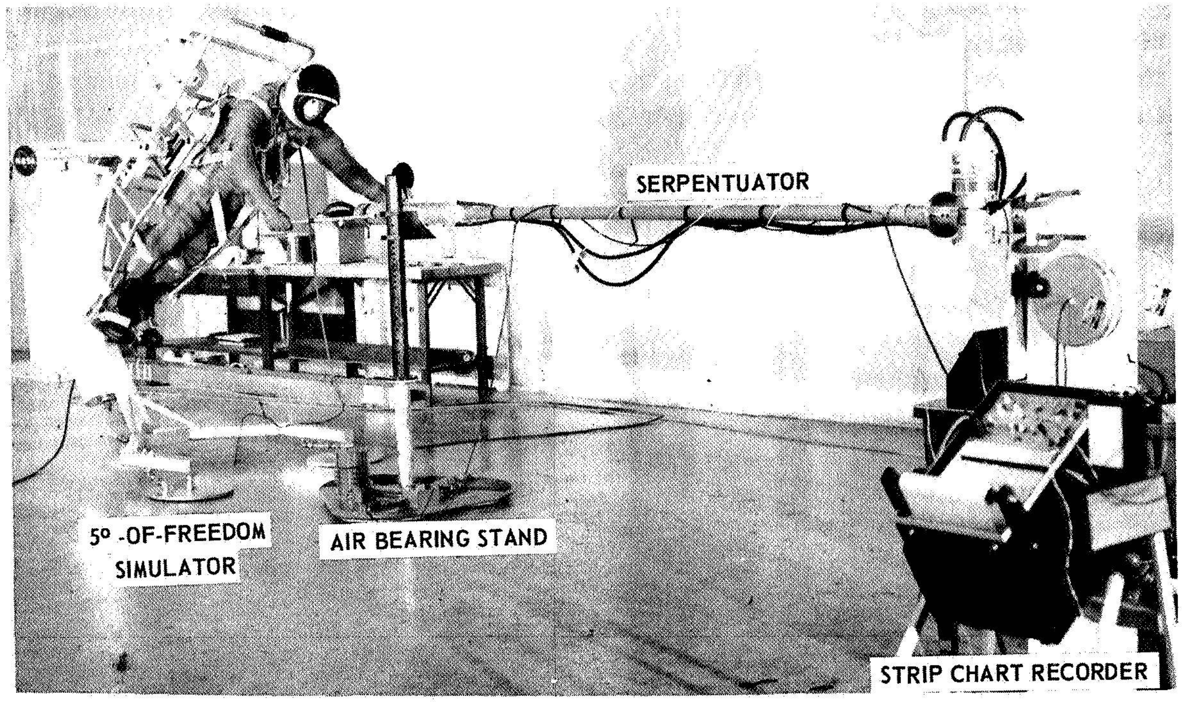

FIGURE 24. TEST SUBJECT OPERATING SERPENTUATOR

The strip chart recorder, also shown in Figure 24 provided a force and position read-out capability for a strain gage and a position potentiometer mounted on the serpentuator. Time-rates of movement were also obtained from the chart.

Evaluation Procedure

Each test subject propelled himself back and forth across both the 0.698-radian (40-degree) and 1.395-radian (80-degree) arcs for several cycles in order to determine normal rates of travel, fatigue points and necessary rest periods. Three orientations of the test subject's body in relationship to the serpentuator were used, and three force settings on the pump handle were evaluated. As mentioned in the equipment description, the serpentuator is equipped with extension tubes of two lengths. With the short extension installed, the serpentuator is in the tip mode, and with the long extension, the base mode. The length of the 0.698-radian (40-degree) movable part of the serpentuator is 4.54 m (14.9 ft) for the base mode and 1.16 m (5.28 ft) for the tip mode. The length of a 1.395-radian (80-degree) arc for the base mode is 6.33 m (20.8 ft) and for the tip mode is 2.26 m (7.4 ft). Tests were conducted with the device in base mode and then repeated in tip mode.

Force and position versus time were simultaneously plotted on the strip chart recorder during all testing. Pump stokes per cycle were obtained from the strip chart force and position graphs. Data sheets and labeled portions of the strip chart are included in Appendix G.

The three orientations used by the test subjects were designated as prone (Fig. 25), vertical (Fig. 26) and trailing (Fig. 27). In the trailing position the test subject's body was allowed to align itself naturally with the direction of motion of the serpentuator's tip.

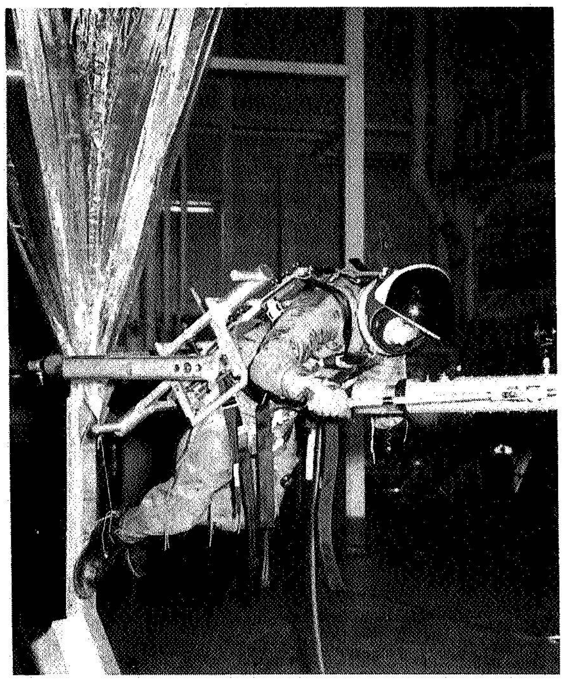

FIGURE 25. TEST SUBJECT IN THE PRONE POSITION

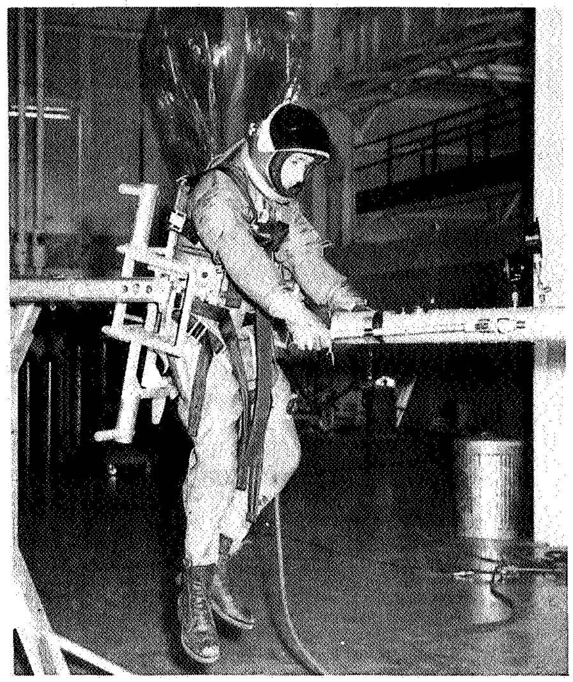

FIGURE 26. TEST SUBJECT IN THE VERTICAL POSITION

Three force settings on the serpentuator hand pump were made by adjusting the ratio of the pump piston travel to the pump handle travel. The different settings were designated as maximum (highest ratio of piston travel to handle travel), nominal (ratio approximately halfway between maximum and minimum), and minimum (lowest ratio).

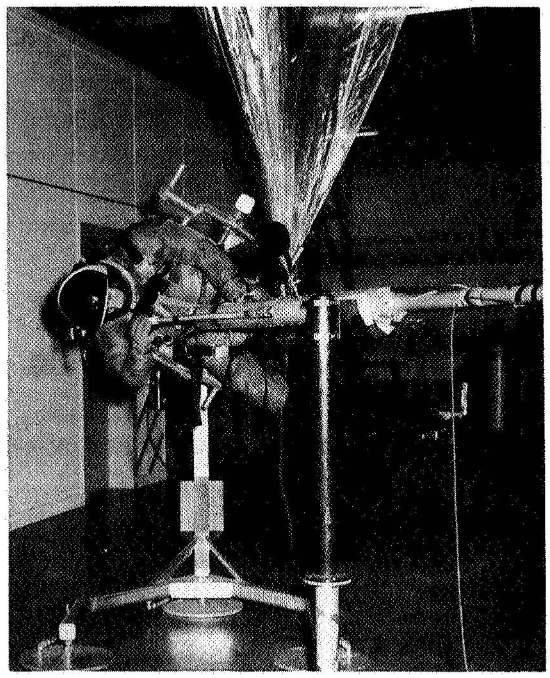

FIGURE 27. TEST SUBJECT IN THE TRAILING POSITION

All test subjects attempted to keep the ease of working the serpentuator at a level of 5 on a 10 point scale, with 1 being very easy and 10 very difficult.

Discussion of Evaluation Results

The maximum force output per stroke at the end of the serpentuator, measured by the force calibrated strain gage, ranged from approximately 20 N (4.5 lb) to 65 N (14.6 lb). Force per stroke typically increased to a maximum value near the beginning of the test subject's motion, then decreased to a nearly uniform value as he moved at a constant speed. Forces listed on the data sheets (Appendix G) under Maximum Force are the maximum values which occur in any one stroke for the given test. Forces under Maximum Force Typical Stroke are an average of several maximum per-stroke values for a normal uniform speed. In some instances greater forces than those occurring during any pump stroke were recorded when the direction control valve was reversed for stopping. In the base mode the maximum force during a typical cycle was usually less than 45 N (10.1 lb), but for the tip mode, the force readings ranged as high as 65 N (14.6 lb). Because the linear velocity was much lower for tip mode operation, it is apparent that considerable error was present in these readings. It was observed that a vertical force on the tube caused wide variations in the force readings for tip mode operation; therefore, the error was probably a result of the test subject's weight being supported in part by the serpentuator tube. The error would be negligible in the base mode because a vertical force would produce much less strain in the longer tube.

Of the three test subject orientations used, no specific one was found to be conclusively superior to the other two. The prone position is relatively inefficient because of the effort required to overcome the greater moment of inertia caused by the greater distance to the center of gravity of the test subject and simulator. The prone position also required more of the test subject's weight to be supported by the simulator chest straps, which added to the discomfort of working the hydraulic pump. In general, the shortest times to traverse the 1.395-radian (80-degree) arc were recorded with the test subject in the trailing position. The trailing position had the advantage of lowest moment of inertia; however, working the pump in this position while in a pressure suit was much more difficult for the test subject than it was in shirtsleeves. Because the use of this position required the test subject to turn through a 1.395-radian (180-degree) angle each time he reversed direction, the times for the 0.698-radian (40-degree) angle with it were usually longer than for the other positions. This was also true for the 1.395-radian (80-degree) runs in tip mode operation. The vertical position has the disadvantage of a greater moment of inertia than the trailing position, but has the advantage that no reorientation is necessary when direction is changed. Another advantage of this position is that the increase in difficulty of working the pump while in a pressure suit is less than for the other two positions.

Several runs were made with each force setting (maximum, nominal, and minimum) in order to determine which one gives the most desirable mechanical advantage. As the data sheets indicate, the time to traverse the 1.395-radian (80-degree) arc was least for maximum force and by far greatest for minimum force. All three test subjects suggested that a force setting even greater than the present maximum would be better, especially in tip mode operation. The maximum force setting seemed obviously better than the other two for all conditions; therefore, it was used exclusively in the remainder of the tests.

Normal rates of travel will vary with each test subject according to size and general physical condition. In the base mode, the average rate of travel for the most rapid shirtsleeve runs was 0.320 m/sec (1.05 ft/sec). The average of the two pressure suit runs was 0.250 m/sec (0.820 ft/sec). For the tip mode, shirtsleeve runs averaged 0.165 m/sec (0.540 ft/sec). For pressure suit runs in the tip mode, the average rate was 0.156 m/sec (0.510 ft/sec). However, some of the specific runs varied more than 30 percent from the average as the data sheets in Appendix G indicate.

The number of cycles a test subject could traverse without fatigue also varied widely, not only from one subject to another, but also from time to time for the same subject. The base mode operation for a pressure suited subject usually tired him in from one to three cycles. The shirtsleeve runs usually continued for three to five cycles. In tip mode operation, test subjects traversed 12 or more cycles in both shirtsleeves and pressure suits before fatigue occurred. Test subjects stated that fatigue was often influenced as much by the discomfort of the simulator as by the exertion of working the hydraulic pump.

The determination of necessary rest periods is a very subjective matter. The time required for a subject to become fully rested varied from about two to five minutes, but the number of cycles he was able to traverse after resting was usually less than the number he traversed continuously before fatigue occurred.

As the data sheets contained in Appendix G show, the times required to traverse the 1.395-radian (80-degree) arc were usually substantially less for a subject in shirtsleeves than in a pressure suit. For base mode operation, the shortest time durations with subject attempting to work at a normal rate were 22 seconds in a pressure suit and 17 seconds in shirtsleeves. The tip mode required the shortest time durations; 13 seconds in a pressure suit and 11 seconds in shirtsleeves. Rates of travel were usually about the same for a given subject in the same position and same dress.

Conclusions and Recommendations

From the results of the mechanical zero-gravity simulation testing of the serpentuator, it appears that the trailing position or some slight modification of it is the most desirable operator orientation for traveling distances of more than 2 m (6.56 ft). For shorter distances the vertical position would probably be faster and allow more precise positioning of the operator in space.

The pump handle force ratio should be increased or made adjustable to higher settings than the present maximum. A much higher ratio would be more efficient in tip mode operation.

Although it is impractical to give definite figures for normal rates of travel, number of continuous cycles possible, and frequency and length of rest periods, the test results do give some idea of probable ranges for these quantities. The limits of these quantities should be expected to vary from those given in the test results if more test subjects were used and if all conditions not actually present in space, such as simulator mass and air bearing drag, were removed.

Continuation of the serpentuator evaluation in the neutral buoyancy tank will overcome some of the limitations of mechanical zero-gravity simulation testing which have been mentioned. Instrumentation for monitoring a test subjects heart rate is available in the neutral buoyancy testing area, and will provide a less subjective means of determining fatigue points and necessary duration of rest periods. A combination of the results of both types of testing is expected to give more reliable predictions of the serpentuator's operating characteristics and capabilities.

"EXSERP" SERPENTUATOR

Introduction

The purpose of this project is to evaluate and demonstrate the usefulness of the "exserp" in providing a means for mechanically connecting space workers and all objects necessary for extravehicular operations to the parent vehicle and Orbital Workshop. In addition, it provides transportation, stabilization, a platform, and a means for rendezvous and docking. The "exserp" can also serve as a flexible tether.

Development

The serpentuator was received in January 1967, and installation made in Building 4755. All support tool design and "out of house" fabrication was completed and installed by the end of March.

In-house serpentuator test using the air bearing platform began in March, and required minor modifications to support equipment. Preliminary testing results were favorable.

All instrumentation and mechanical support tooling was installed, calibrated, and proof tested satisfactorily during April and May. Evaluation testing began and static, dynamic basic tests were completed. Basic data and tapes were forwarded to the Computation Laboratory for interpretation.

Evaluation testing involving static and dynamic tests was completed during June and July 1967.

Upon completion of test procedures, the serpentuator developed minor electrical and mechanical problems which were corrected.

During August and September, the serpentuator was returned to the original manufacturer for evaluation of wear then sent back to MSFC for further testing and evaluation.

In October and November, the "exserp" (five-link) serpentuator was assembled to the air bearing platforms and tested. Preliminary testing indicated that a greater acceleration force was needed for moving masses over 81.7 kg (180 lb). However, this upgrading was not accomplished until the system was demonstrated and operated by MSC flight personnel, astronauts McCandless and Lousma. The basic system appeared to be favorably accepted. The "exserp" system was upgraded to provide greater acceleration and link force, and in addition, the controls were upgraded to provide infinite sensitivity. The upgraded "exserp" and air bearing systems were demonstrated to and favorably accepted by management and design engineering personnel of MSFC's Astrionics and Propulsion and Vehicle Engineering Laboratories.

A final testing program for evaluating the "exserp" was established to determine static and dynamic horizontal tip forces.

Test Procedure

A manned T50-2 air bearing platform attached for static and dynamic horizontal forces was used for evaluation tests of five-link mechanical "exserp" serpentuator. The "exserp" test (Table XVIII) utilized the air bearing platform to:

1. Determine the static force required to initiate motion with the electrical power off.

2. Determine the dynamic force required to maintain motion with the electrical power off.

3. Determine tip force with the variable power control in the maximum, nominal, and minimum positions, with the electrical power "on" and the directional lever to its maximum position and the "exserp" in the straight position.

4. Determine tip force with the variable power control in the maximum, nominal, and minimum positions, with the electrical power "on" and the directional lever to its maximum position and the "exserp" in the 40-degree position.

TABLE XVIII. "EXSERP" TEST RESULTS

Forces	Position	Electrical Power	Variable Power Control	Results kg (lb)
Static	Straight	Off		1.02 (2.25)
Static	40 degree	Off		1.13 (2.50)
Dynamic	Straight	Off		0.113 (0.25)
Dynamic	40 degree	Off		0.227 (0.50)
Static	Straight	On	Minimum	3.06 (6.75)
Static	Straight	On	Nominal	3.18 (7.0)
Static	Straight	On	Maximum	3.29 (7.25)
Static	40 degree	On	Minimum	4.98 (11.0)
Static	40 degree	On	Nominal	5.44 (12.0)
Static	40 degree	On	Maximum	5.44 (12.0)

NOTE: Static data was taken in base mode and measurements taken on tip. The variable power control denotes the sensitivity.

RENDEZVOUS AND CAPTURE SIMULATOR

Summary

Evaluation testing of the rendezvous and capture simulator indicated the design concept is basically sound. The simulator is supported on air pads, propelled and maneuvered by compressed air thrusters, and is used to simulate short range work between orbiting equipment.

Maneuverability was hampered because of the high mass/thrust ratio and limited duration of operating time. Thrust and/or operating time are insufficient to allow all the necessary steering corrections for misalignment and drifting, a condition aggravated by floor irregularities which affect air pad operation.

A new design incorporating some of the following features to allow longer operating time or higher velocities is recommended: lighter weight, outside compressed air source, and some other thruster power source.

Simulator Description

The simulator is a vehicle used for simulation of rendezvous, capture, and docking of orbiting equipment.

It floats above a floor on air cushion pads provided with air from two self-contained air cylinders. The vehicle is propelled and braked by compressed air thrusters mounted around its perimeter and uses an aircraft type control stick for maneuvering. Pushing the stick in the desired direction of travel operates electrical solenoid valves, supplying compressed air to the respective thruster nozzles, providing thrust for maneuvering and braking. Braking is accomplished by pushing the control stick opposite to the direction of motion. Two pushbuttom switches on the stick operate the respective thrusters to affect clockwise or counter-clockwise rotation. Figures 28 through 31 illustrate the correlation of control operation and resultant maneuvers. Thruster air is contained in a high pressure spherical vessel mounted on the simulator. Figure 32 depicts the simulator and Figure 33 illustrates the instrument panel and controls.

Lead-acid batteries, supplying 30 Vdc, provide power for the electrical equipment.

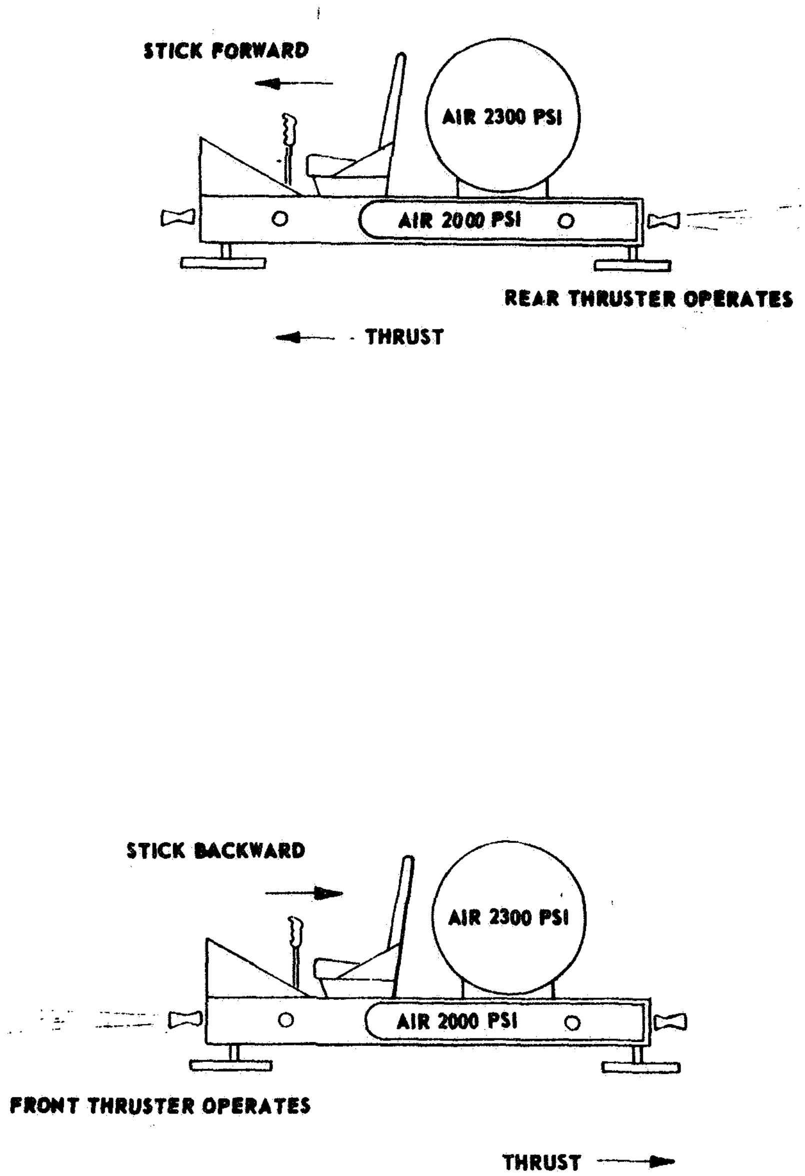

FIGURE 28. FORWARD AND BACKWARD CONTROL CONFIGURATIONS

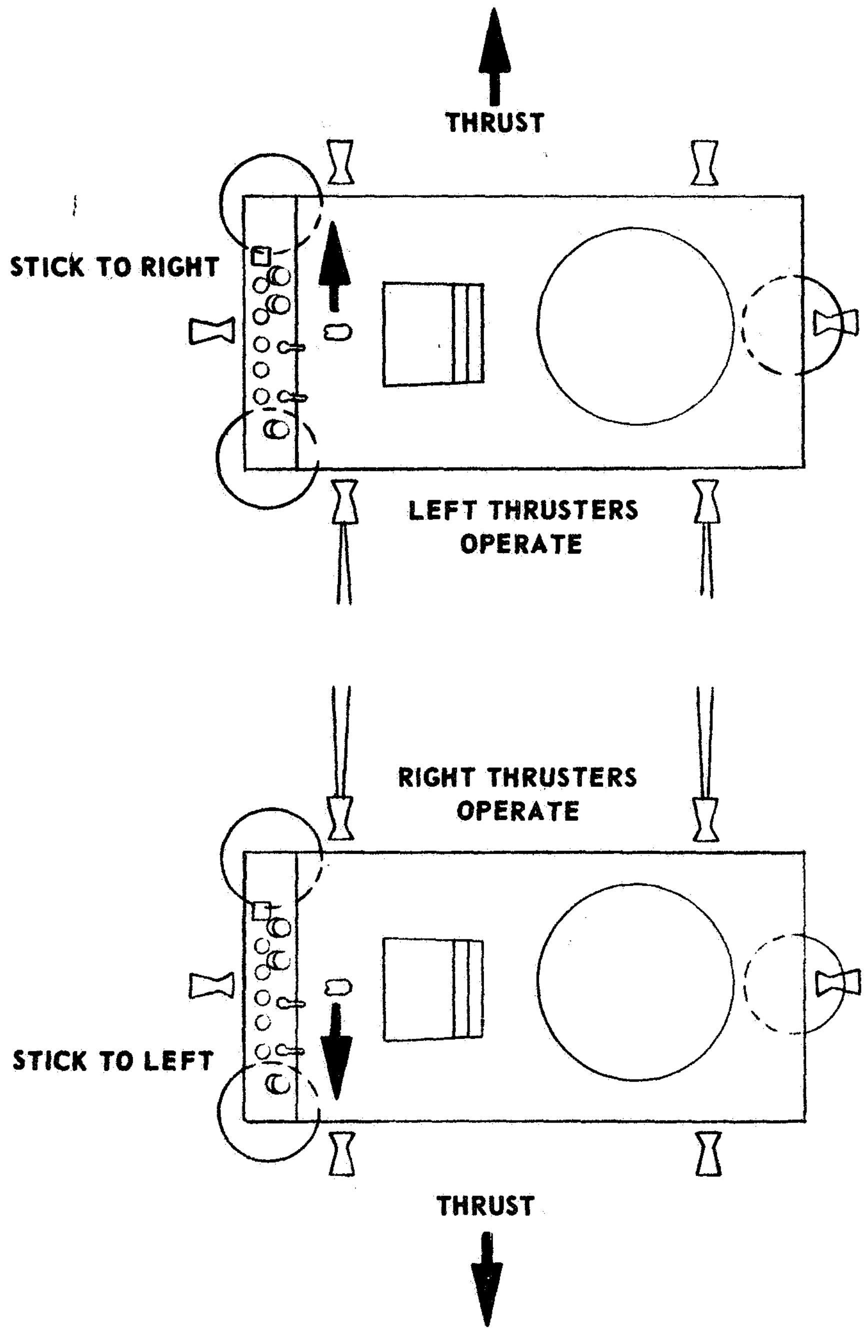

FIGURE 29. LEFT AND RIGHT CONTROL CONFIGURATIONS

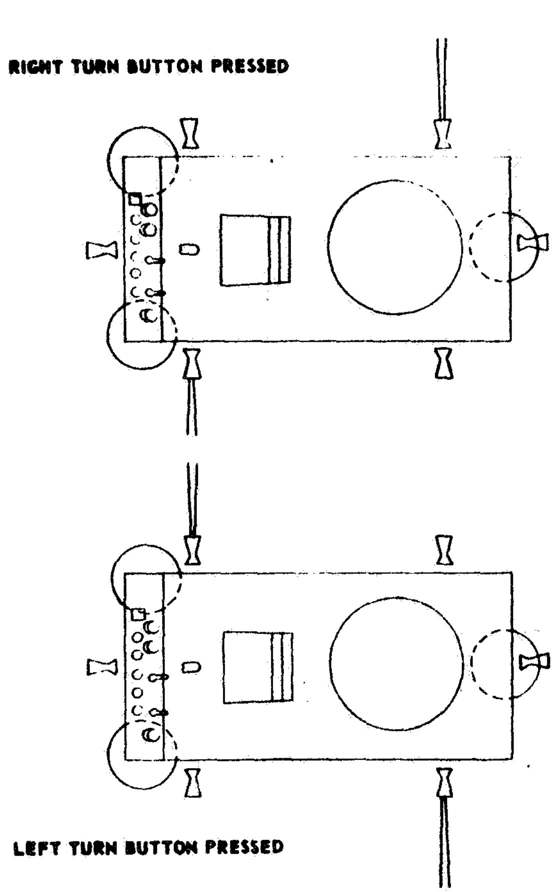

FIGURE 30. CONTROL CONFIGURATIONS FOR LEFT AND RIGHT TURNS

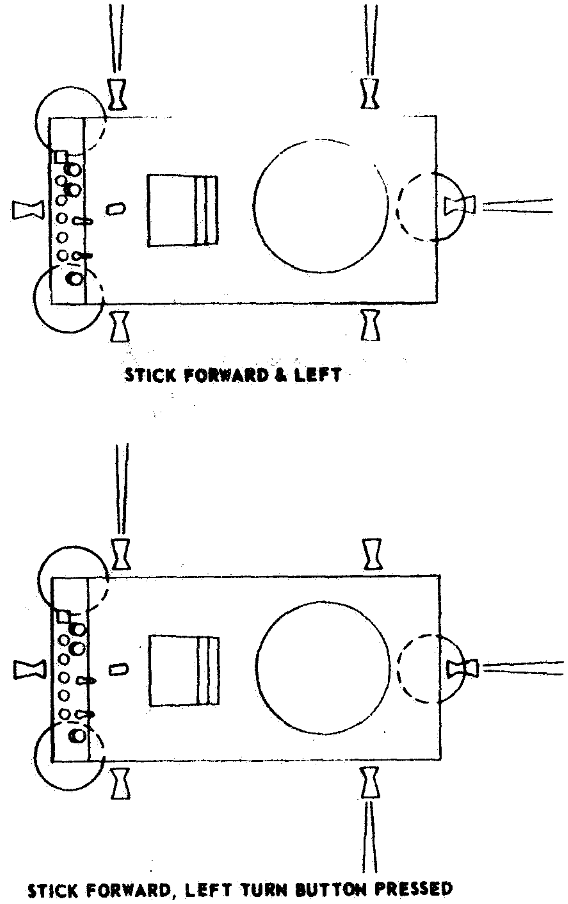

FIGURE 31. TYPICAL COMBINATIONS OF CONTROL CONFIGURATIONS

Evaluation Procedure

PRE-FLIGHT PROCEDURE

1. Check electrical system by depressing the "press to test" button and reading voltmeter. Meter should indicate 30 Vdc. Charge batteries with supplied battery charger, if necessary.

2. Pressurize air bearing cylinders to 1.375×10^7 N/m^2 (2000 psi).

3. Pressurize thruster sphere to 1.585×10^7 N/m^2 (2300 psi).

4. Switch on:

(1) Translational control switch

(2) Main power switch

NOTE: It is important to switch on translational control switch before main power switch because relays hold the thruster solenoids normally open until the translational control switch is on. Switching on main power first allows thrusters to operate, wasting compressed air.

(3) LV-1 and LV-2 switches, opening air circuits to thruster valves.

(4) CW and CCW rotation shut off to "on" position.

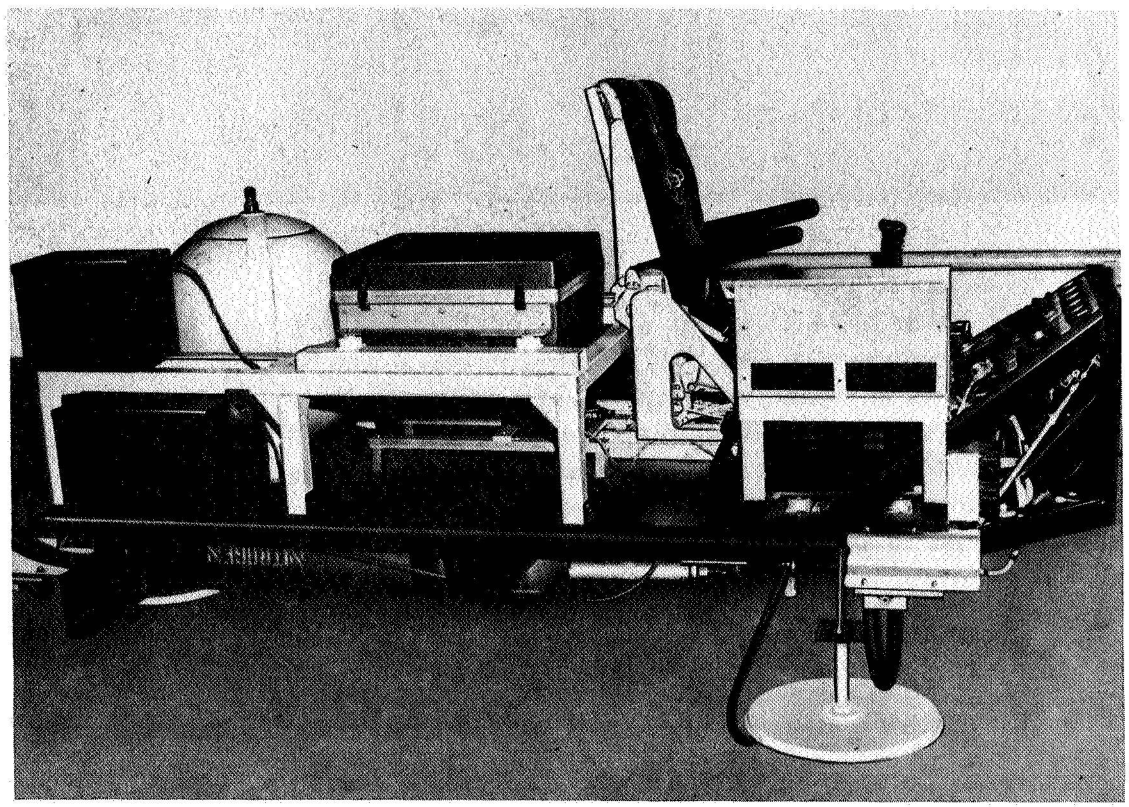

FIGURE 32. RENDEZVOUS AND CAPTURE SIMULATOR

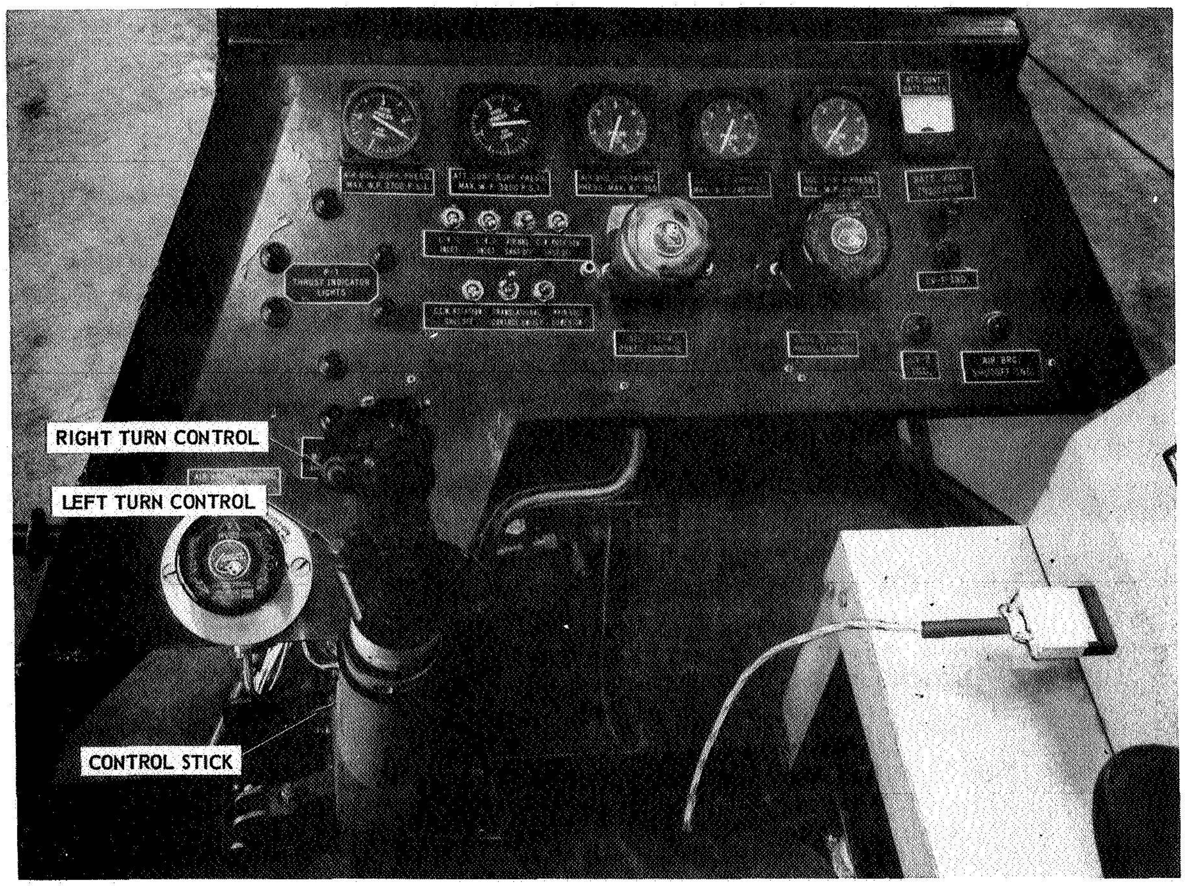

FIGURE 33. INSTRUMENT PANEL

5. Open LV-1 regulator while observing the LV-1 regulator pressure gage. Set pressure at 1.585×10^6 N/m^2 (230 psi). The thruster regulator valves automatically vent, or "pop off" at 1.655×10^6 N/m^2 (240 psi) limiting the maximum pressure setting to approximately 1.585×10^6 N/m^2 (230 psi). Regulator setting is a sensitive operation and must be done with care to avoid possible damage to the regulator or waste of compressed air. Twist the knob clockwise in small increments until the gage indicates a specified setting.

6. Open LV-2 regulator until LV-2 gage indicates 1.585×10^6 N/m^2 (230 psi).

7. Open air pad regulator until air pad pressure gage indicates 6.90×10^5 N/m^2 (100 psi).

8. The vehicle is now ready for operation; however, it must be held stationary when the air pads are activated. The air pad switch when "off" serves to keep the vehicle from drifting.

9. Activate the air pad switch when ready to operate vehicle.

NOTE: The air pad switch functions as an emergency braking mechanism in the event the simulator approaches an obstacle. At maximum velocity 0.76 m/sec (2.5 ft/sec), switching off the air pads will stop the simulator within approximately 1.8 m (6 ft).

TEST MEASUREMENTS

The data obtained from the evaluation described herein are presented in Table XIX.

THRUST — The average maximum thrust available, as measured by a spring scale attached between the simulator and a fixed post, was 44.5 N (10 lb).

MASS — The simulator was weighed by lifting it with a hoist and reading a dynamometer connected between the hoist and the simulator. Because of the large scale of the dynamometer, 0 to 88 960 N (0 to 20 000 lb), the measurement obtained (727 kg [49.8 slugs]) is considered to be no more accurate than 4.54 kg (0.31 slugs).

DRAG — Performance of the air pads was considered a satisfactory means of providing low drag. The test procedure was to attach one end of spring scales to the vehicle, activate the air pads, and allow the vehicle to come to a rest, if drifting. Pulling force was steadily applied to the free end of the scales, parallel to the floor, until starting friction was overcome. When motion of the simulator was detected, the indicated force was observed and recorded. Variations in floor levelness and texture, as well as inherent inaccuracies of the spring scale measuring technique, can account for differences in drag data.

Experimentation with regulator pressures indicated that settings as low as 2.07×10^5 to 5.16×10^5 N/m^2 (35 to 75 psi) floated the vehicle. However, a setting of 6.90×10^5 N/m^2 (100 psi) was used in all test trials to assure optimum operation of the air pads and economy of the compressed air supply.

TABLE XIX. RENDEZVOUS AND CAPTURE VEHICLE EVALUATION DATA

1. Force: 44.5 N (10 lb)   2. Mass: 727 kg (49.8 slugs)

3. Drag: Forward 6.68 N (1.50 lb)   Reverse 6.68 N (1.50 lb)
Left 4.45 N (1.00 lb)   Right 12.25 N (2.75 lb)

4. Acceleration: a = F/M

$$\frac{44.5 \text{ N } (10 \text{ lb})}{727 \text{ kg } (49.8 \text{ slugs})} = 0.61 \text{ m/sec}^2 \ (0.19 \text{ ft/sec}^2)$$

Velocity - m/sec (ft/sec)

Trial No.	Factors	Distance m (ft) 3.05 (10)	6.10 (20)	9.15 (30)	12.20 (40)	15.20 (50)
1	Time (sec)	12.05	17.0	23.0	28.0	35.0
	Velocity	0.488 (1.49)	0.720 (2.19)	0.796 (2.43)	0.87 (2.66)	0.87 (2.66)
2	Time	15.0	21.0	27.0	31.0	35.0
	Velocity	0.406 (1.24)	0.58 (1.77)	0.68 (2.07)	0.787 (2.4)	0.87 (2.66)
3	Time	16.0	22.0	27.0	31.0	35.0
	Velocity	0.38 (1.16)	0.555 (1.69)	0.68 (2.07)	0.787 (2.4)	0.87 (2.66)

5. Maximum Velocity: 0.87 m/sec (2.66 ft/sec)

6. Turning Circle: 0.61 to 0.915 (2 to 3 ft)

7. Braking: Velocity m/sec (ft/sec) - Stopping Distance m (ft)

Velocity m/sec (ft/sec)	Stopping Distance m (ft)
0.7620 (2.50)	7.924 (26)
0.7620 (2.50)	7.924 (26)
0.6096 (2.00)	6.096 (20)

ACCELERATION, VELOCITY, AND BRAKING — A course for maneuver was prepared on a smooth concrete floor and intervals of 3.1 m (10 ft) were marked by tape for a total course length of 15.2 m (50 ft). Several trials were completed, attempting to drive the vehicle in a straight line along the course with maximum thrust being applied. The elapsed time at each interval mark was recorded. The velocity at each mark was estimated by averaging the effective velocities for the preceding and following 3.1 m (10 ft) distances.

With these velocities determined, braking trials were made, driving the vehicle at maximum thrust for the required distance to reach a known velocity. At the mark, thrust was applied opposite to the direction of travel, and the stopping distance measured.

TURNING CIRCLE AND MANEUVERABILITY – Due to the turn control arrangement, the simulator should be capable of turning with zero radius about an axis if the center of gravity location, thruster orientation, and drag conditions are ideal. Trials show that the diameter of the tightest turning circle possible is 0.6 to 0.9 m (2 to 3 ft).

CONCLUSIONS AND RECOMMENDATIONS

There are two features which create serious disadvantages in useful testing of the simulator as a docking vehicle. The vehicle mass is excessive; therefore, the thruster force required for motion drains the compressed air supply after a short period of operation. The self-contained air supply concept seems more feasible for a lighter weight vehicle or a vehicle having the thruster air supplied by a trailing flexible line and the air pads operated by a trailing power cord to an integral air pump.

Extremely short travel required of the control stick to operate the micro-switches makes control too sensitive and frequently causes unintentional operation of some thrusters. Increased free travel of the stick before switches are closed should be sufficient.

A more logical location and operation of the turning control is desirable. Consideration should be given to thumb switches on the left and right side of the stick or the conventional rudder pedals to operate the turning controls.

Considerable correction with controls is necessary to maintain direction and heading. Probably, the greatest cause of this is insufficient thrust to overcome the varying drag forces and irregularity of the floor surface. This test indicates that these problems could be overcome in a new design incorporating some of the following features:

a. low total mass of vehicle

b. compressed air source for aid pads and thrusters other than that carried aboard vehicle

c. thruster power source other than compressed air

APPENDIX A

ENGINEERING TEST PLAN FOR STORABLE TUBULAR EXTENDIBLE MEMBERS

RESEARCH AND ENGINEERING PROJECT - WORKSCOPE	M - ME-M	PROJECT NUMBER: EP-5106

TITLE:

ENGINEERING TEST PLAN FOR STORABLE TUBULAR EXTENDIBLE MEMBERS (STEM)

MANUFACTURING ENGINEERING DIVISION

MSFC NASA

PURPOSE OF PROJECT:

1. The purpose of this Engineering Plan is to verify and develop the capabilities of the DeHavilland STEM Model A-32 for use as a tool handling device.

   Determing the extend of controllability for the tool handling claw will be one of the prime objectives of this evaluation. This will consist of performing various maintenance and repair tasks both in weightless (zero-g) and semi-weightless (one-g) conditions.

REQUIRED ACTION:

2. Investigate and develop a design concept for a tooling handling device (claw).

3. Tasks are to be performed using an air bearing cart.

4. This task will be performed under the following conditions;

   a. One-g shirtsleeve
   b. One-g pressurized suit
   c. Martin five-degree-of-freedom simulator (shirtsleeve)
   d. Martin five-degree-of-freedom simulator (pressurized)
   e. Air bearing cart

   Each task will be performed at least once without the tethering system to determine the level of difficulty for that task.

   The same subject will perform the test under all conditions providing a correlation of data between each of the conditions. The data will consist of ease of handling material under each condition, time required to perform each task, and comments on problem areas.

REQUESTED BY:	ESTABLISHED BY:	APPROVED BY	PROJECT ENGINEER:	
P. H. Schuerer	H. T. Blaise	J. P. Orr	M. Gonz, Jr.	
DATE:	DATE:	DATE:	DATE ASSIGNED:	DATE STARTED:

MAN HOURS ---	ESTIMATED:	EFFORT:	EQUIPMENT COST ---	ESTIMATED:	LAUNCH VEHICLE PROGRAM
COMPLETION DATE ---	ESTIMATED:		MATERIAL COST ---	ESTIMATED:	PROJECT PRIORITY

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5. DETAIL TEST DESCRIPTION

The test will consist of maneuvering the STEM into a position whereby an evaluation of the STEM tool handling capabilities can be made. The subject will maneuver the STEM within its extended length 4.8 m (15.6 ft) and attempt to verify its design capabilities. To perform these evaluation tests, the following tools and equipment will be required:

a. Craftsman push release ratchet
b. Modified "yankee" screwdriver
c. T-handle gauntlet
d. Inertia wheel tool
e. Space impact wrench

NOTE: When performing each task it will be necessary to attach a helium filled balloon to the extended STEM in a manner that will simulate a weightless condition and prevent the boom from bending under various weights of tools.

6. TEST I: One-g Shirtsleeve Test Conditions

First familiarize the subject with manipulaton of the STEM in this environment.

a. Extend the STEM out to the task board, pick up the desired tool, and retrieve it.

b. To test the subjects grasp, remove the tool from the STEM, and reattach the tool to the STEM.

c. To further test the STEMS capability for handling tools and evaluate the subjects proficiencies, extend the boom to a position where another test subject could remove the tool from the STEM, then replace the tool on the STEM.

d. The test subject then maneuvers the STEM and returns the tool to the task board.

e. Repeat steps A through D for each tool mounted on the task board.

7. TEST II: One-g Pressurized Suit

Familiarize the subject with manipulating the STEM in this environment. Repeat steps a through e of Test I.

8. TEST III: Martin Five-Degree-of-Freedom Simulator (shirtsleeve)

Familiarize the subject with manipulating the STEM in this environment. Repeat steps a through e of Test I.

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9. TEST IV: Martin Five-Degree-of-Freedom (pressurized suit)

Familiarize the subject with manipulating the STEM in this environment. Repeat steps a through e of Test I.

10. TEST V: Air Bearing Cart

Familiarize the subject with maneuvering and manipulating the STEM in this environment. Repeat steps a through e of Test I.

11. TEST VI: Droop computation minus claw attachment and balloon support.

   a. Conditions
      1. STEM fully retracted
      2. Horizontal reference axis established
      3. Reference axis measured in 0.31 m (1 ft) increments

   b. Extend the STEM end to each increment of the horizontal reference axis, measure and record, in meters, the vertical distance.

   c. Plot resulting data.

12. TEST VII: Droop computation with claw attachment

   a. Repeat steps a through c of Test VI

The engineering plan for water immersion testing was eliminated after confirming with the engineering staff of DeHavilland Aircraft of Canada, Limited. They advised against such testing with model A-32 due to inadequate water seals.

13. SCHEDULE: Tenative test schedule for evaluation of the DeHavilland STEM as a tool handling device.

1.	One-g shirtsleeve	2 Men	1 Day
2.	One-g pressurized suit	2 Men	2 Days
3.	Five-degree-of-freedom simulator (shirtsleeve)	3 Men	2 Days
4.	Five-degree-of-freedom simulator (pressurized suit)	3 Men	3 Days
5.	Air bearing cart	3 Men	2 Days

NOTE: Tentative dates subject to the completion and availability of test personnel, space tools, facilities and necessary equipment.

14. FUNDING CODE:

Procurement: 124-08-01-0608-25-8-004-030
Labor: 124-08-01-0600-25-00-030

ENGINEERING PROJECT	SHEET OF	PROJECT NUMBER	

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APPENDIX B

EVALUATION TEST PLAN FOR THE THRUSTER ASSEMBLY

RESEARCH AND ENGINEERING PROJECT - WORKSCOPE	M - ME	PROJECT NUMBER:

TITLE:

EVALUATION TEST PLAN FOR THE THRUSTER ASSEMBLY

MANUFACTURING ENGINEERING DIVISION

MSFC NASA

PURPOSE OF PROJECT:

The evaluation was conducted to determine the propelling capabilities of the thruster assembly mounted on an air bearing test cart, including maximum stationary thrust, maximum acceleration, maximum velocity, and the ratio of time in operation to amount of propellant consumed.

Thruster assemblies of this type will be used as a means of propulsion on the air bearing test system for the manipulator/controller module (a maneuvering unit with a master-slave grappler arm attached).

REQUIRED ACTION:

Properties of the thruster assembly mounted on an air bearing cart which are to be determined include:

1. Maximum stationary thrust
2. Maximum acceleration
3. Maximum velocity
4. Mass of thruster assembly and test cart combined
5. Drag on air bearing cart and thruster assembly combination
6. Time-rate of thruster propellant consumption

Procedures for determining the above listed properties are outlined below:

1. Maximum stationary thrust will be determined by attaching one end of a small spring scale (thrust should be in the range of 8.9 to 22.2 N [2 to 5 lb]) to the cart-mounted thruster assembly, and anchoring the other end to a stationary body at the same height as the attachment point on the cart. With the nozzle pressure regulator adjusted for maximum pressure, the solenoid will be activated and thrusting force will be observed on the scale.

REQUESTED BY:	ESTABLISHED BY:	APPROVED BY	PROJECT ENGINEER:	
DATE:	DATE:	DATE:	DATE ASSIGNED:	DATE STARTED:

MAN HOURS ---	ESTIMATED:	EFFORT:	EQUIPMENT COST ---	ESTIMATED:	LAUNCH VEHICLE PROGRAM
COMPLETION DATE ---	ESTIMATED:		MATERIAL COST ---	ESTIMATED:	PROJECT PRIORITY

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2. Acceleration is assumed to be constant (a reasonable assumption for velocities much less than maximum velocity, since wind resistance and change in surface drag are small and the thrusting force is almost constant); therefore, the maximum acceleration will be determined by utilizing maximum thrust and measuring the time required to start from zero velocity and traverse a distance less than that required to reach maximum velocity. The numerical value of acceleration is twice the value of the distance traversed divided by the elapsed time. To insure that maximum velocity is not approached in the distance used, measurements will be made over several distances separated by increments of approximately 3.05 m (10 ft), and results will be compared.

   Acceleration may be determined theoretically from the equation $a = F/M$, where F is the maximum thrust and M is the mass of the entire system. A slight difference in the values of acceleration is to be expected, because: (1) wind resistance and bearing drag are neglected in the theoretical calculation, and (2) the thrusting force is not actually constant (force and velocity are inversely related).

3. Maximum velocity will be determined by activating the thruster solenoid with the test cart directed in a path marked in 3.1 m (10 ft) intervals, and measuring the time required to traverse an interval after maximum velocity has been reached. Times will be recorded for several distance-intervals and compared to determine whether the velocity was maximum.

4. The mass of the thruster and cart will be determined by weighing the entire assembly and dividing by the gravitational acceleration to convert weight to mass.

5. Drag of the air bearings will be determined by attaching a small spring scale to the cart, with the air pads operating but with the thruster off. The force required to set the assembly in motion will be recorded. Measurement will be made only in the forward direction because the assembly will be uni-directional.

6. The time-rate of propellant consumption will be determined by charging the propellant tank with a given amount of propellant and measuring the time required for the propellant to be exhausted. The thruster nozzle pressure will be regulated at the maximum value for this test, and the cart assembly will be held by a restraint.

EQUIPMENT AND FACILITIES:

1. Thruster assembly, air bearing test cart and other necessary support equipment
2. Stop watch
3. Small spring scale 44.5 N (10 lb)
4. Large platform scale 4448.2 N (1000 lb)
5. Steel tape measure 15.2 m (50 ft)
6. Restraint rope

7. Smooth surface at least 3.05 m (10 ft) wide and 15.2 m (50 ft) long.

APPENDIX C

ENGINEERING EVALUATION: BLOWER MOTOR PERFORMANCE PARAMETERS

APPENDIX C

ENGINEERING EVALUATION: BLOWER MOTOR PERFORMANCE PARAMETERS

The data presented in Appendix C was extracted from a report prepared for NASA/MSFC by the Space and Information System Division of North American Rockwell, Inc., dated August 4, 1968 (WN-0385)

Purpose of Evaluation

This evaluation was made to determine the operational characteristics of a blower motor in a plenum and air distribution breadboard representing the NASA T50-2 air bearing platform design approach. The specific characteristic being investigated was the feasibility of pad air pressure control by the varying of applied motor voltages.

Test Equipment

Blower (Fig. C-1) incorporating a type 115-250 blower

Hovair type XD 16014 air pad

HP 400H VTVM RMS voltmeter

1.002 ohm resistor (current shunt)

Duragage type pressure gage (0 to 103 425 N/m^2 [0 to 15 psi])

Fischer-Portor flow meter (0.52 m [6 in.], 0 to 0.0133 m^3/sec [0 to 29 scfm])

Copper-Constantin thermocouples

Lewis Engineering Instrument Company thermocouple switch

L&N type 8692 temperature potentiometer

Variac GR type W5MT (115 V, 60 cps)

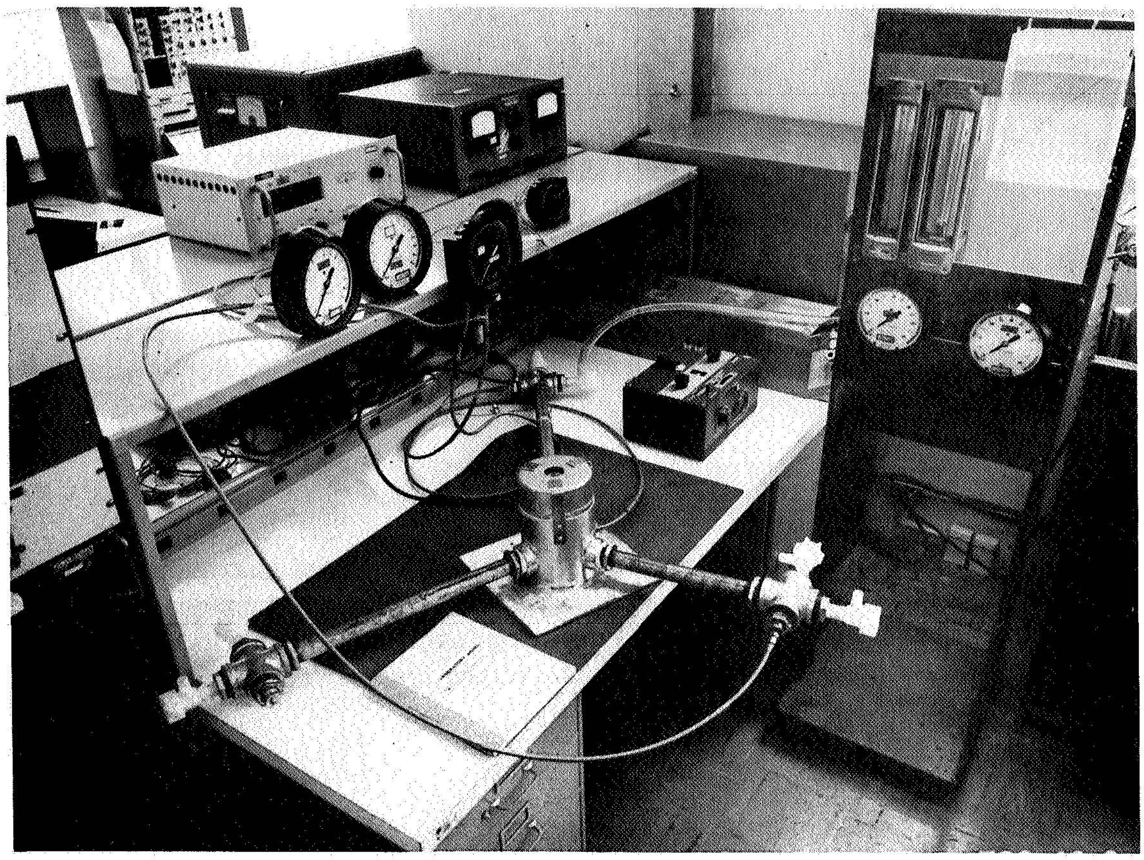

FIGURE C-1. BLOWER

Evaluation Procedure

A schematic of the evaluation test equipment setup is presented in Figure C-2. A nominal air pad performance condition was accomplished by flowing air with minimum restriction through the air pad loaded with a 104.33 kg (230 lb) weight and adjusting to the minimum required applied motor voltage to float the pad at a low friction level. The plenum pressure was 6894 N/m^2 (1.0 psi) at this condition. Pad flow was determined by diverting all the air flow from the pad through the flow meter.

With an applied voltage sufficient to float one pad with the 104.33 kg (230 lb) load, the flow at the valve was restricted until the plenum pressure was 3894 N/m^2 (1.0 psi). This flow, for one pad, was then measured as 0.00141 m^3/sec (3 scfm relative).

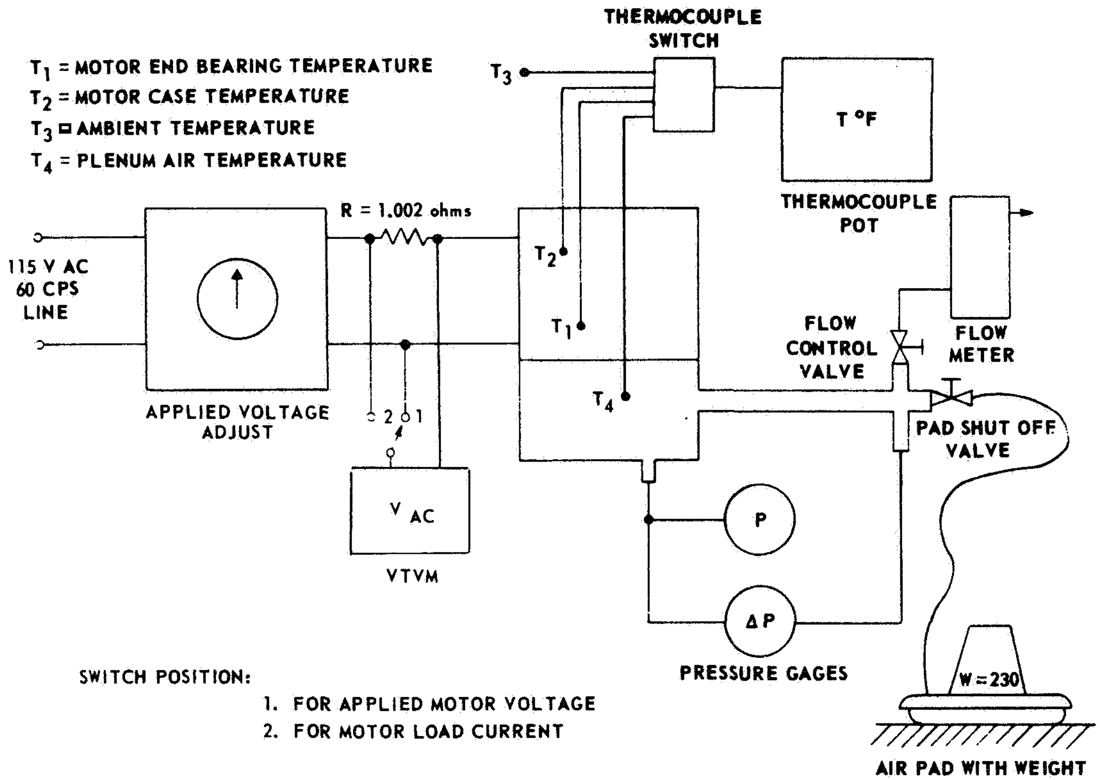

FIGURE C-2. EVALUATION EXPERIMENT SETUP

A nominal three pad flow condition was established as 0.00425 m^3/sec (9 scfm) at 3894 N/m^2 (1.0 psi) to float a load using 0.00141 m^3/sec (3 scfm) at 3894 N/m^2 (1.0 psi).

The evaluation was continued by varying the applied voltage and restrictor valve setting to maintain a constant flow of 0.00425 m^3/sec (9 scfm). Motor load current, stabilized temperatures, and pressures were measured for each setting. The same constant flow evaluations were re-run for 0.00566 m^3/sec (12 scfm) and 0.00708 m^3/sec (15 scfm).

Conclusions and Recommendations

Data obtained in the test runs are presented in Table C-I and illustrated in Figure C-3. The figure indicates the voltage applied to the blower motor offers significant control of air pressures delivered.

TABLE C-I. EVALUATION DATA

Applied Voltage	Flow = 9 scfm							Flow = 12 scfm							Flow = 15 scfm						
	P	I_{ac}	T_1	T_2	T_3	T_4	VA	P	I_{ac}	T_1	T_2	T_3	T_4	VA	P	I_{ac}	T_1	T_2	T_3	T_4	VA
47	0.7	2.5	102	90	70	95.5	118														
60	1.0	3.0	110	97.5	70	103.5	180														
66	-	-	-	-	-	-	-	1.1	3.2					211							
70	1.2	3.2	118	105	69	112	224	1.15	3.4					238							
80	1.5	3.6	127	114	685	121	288	1.4	3.8					304							
80.5	-	-	-	-	-	-	-	-	-					-	1.5	4.2	125	110	74	120	338
90	1.75	4.0	142	130	73	135	360	1.8	4.2					378	1.65	4.4	128	115	74	124	396
100	2.05	4.3	152	137.5	70	144	430	1.95	4.6					460	2.0	4.8	145	130	74	138	480
110	2.5	4.8	167.5	152	70	159	528	2.35	5.0					550	2.25	5.2	154.5	138	75.5	147	572
120	2.75	5.1	181	165	70.5	173	612	2.6	5.4	171	154	71	163	648	2.4	5.5	166	146	76	157	660

NOTES:
1. P is plenum pressure in psig
2. T_1 is motor end-bearing temperature °F
   T_2 is motor care temperature °F
   T_3 is ambient temperature °F
   T_4 is plenum air temperature °F
3. Odd voltage applied values are result of minimum voltages to provide flow required
4. Only 120V setting temperature taken on 12 scfm run

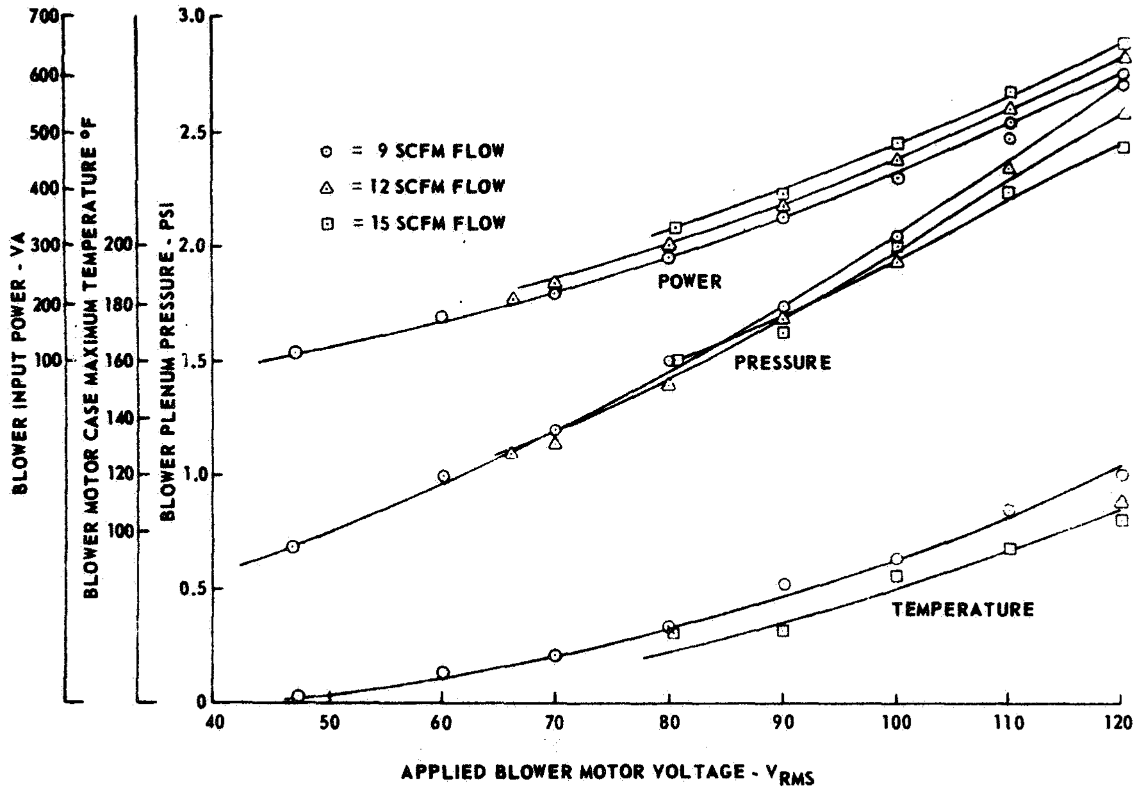

FIGURE C-3. BLOWER PERFORMANCE PARAMETERS VERSUS APPLIED INPUT VOLTAGE WITH CONSTANT OUTPUT AIR FLOW TEST (Date: July 31, 1967)

Temperature rise of the blower as measured at the frame end bearing is well within the allowable +328°K (+65°C). As expected for a given pressure setting, higher flow demand only increases the volt-amp power input to the motor. Greater flow also induces more motor cooling due to increase air flowing through the motor frame.

It is recommended that the T50-2 air bearing platform blower motor be voltage controlled to permit setting of operating lift. This adjustment of applied voltage gives the operator a simple control over the previously difficult parameter adjustments of pressure, and correlated air flow and lift. This is accomplished by the use of a variable voltage transformer or through the use of an SCR motor speed controller.

APPENDIX D

CORRESPONDENCE

INTERNAL LETTER
North American Aviation, Inc.

67-092-EVA-140
Date . 12 October 1967

TO . A. Rothenberg
Address . D/896
AA33

FROM . H. Fornoff
Address . D/092-120
BB28

Phone . 4667

Subject New Technology Reporting Requirements
Contract NAS8-20855, G.O. 02202

In accordance with your letter of 7 July 1967, the attached IL was this day forwarded to the Technology Utilization Group, Attention: R. H. Paul.

H. Fornoff

H. Fornoff
Program Development Manager
Space Maneuvering Devices
Research, Engineering & Test

DW/db

cc: J. Mahoney

INTERNAL LETTER
North American Aviation, Inc.

			67-092-EVA-139
		Date	12 October 1967
TO Address	Technology Utilization Group Attn: R. H. Paul D/096-530 GB63	**FROM** Address	H. Fornoff D/092-120 BB28
		Phone	4667

Subject New Technology Reporting Requirements
Contract NAS8-20855, G.O. 02202

In accordance with instructions received from Allan Rothenberg, IL dated 7 July 1967, subject as above to H. Fornoff, you are advised that there are no patentable inventions or disclosures emanating from this contract.

There was one significant investigation conducted on or about 31 July in the presence of the NASA COR, H. T. Blaise. This investigation concerned itself with the pressure control of an electrically driven air pump, by means of voltage control of the motor. Normally, pressure is controlled by constrictions in the downstream side. This limits the volume of air across the electric motor, the motor overheats and burns out. By reducing the voltage I^2R losses are reduced at about the same rate that the volume of cooling air is reduced.

The test results are reported in the attached WN-0385. The reduction to practice is shown in drawing M0001047, Sheet 2, released by EO 638167, attached.

The Project Engineer, D. Wolkov, advises that there are no other disclosures to be made.

H. Fornoff
H. Fornoff
Program Development Manager
Space Maneuvering Devices
Research, Engineering & Test

DW/db

cc: J. Mahoney
A. Rothenberg

Enc: WN-0385
Drawing M0001047

APPENDIX E

PROOF PROCEDURE MODEL T50-2 AIR BEARING PLATFORM

APPENDIX E

PROOF PROCEDURE (ACCEPTANCE TEST) MODEL T50-2 AIR BEARING PLATFORM

The data presented in Appendix E was extracted from a report prepared for NASA/MSFC by the Space and Information Division of North American Rockwell, Inc., dated October 23, 1967 (SMD-0384-2).

Introduction

The T50-2 bearing platform (Fig. E-1) was designed to support a nominal 90.6 kg (200 lb) and is an equilateral 0.91 m (3 ft) triangular configuration composed of 0.0318 m (1.25 in.) aluminum tubing covered with 0.0032 m (0.125 in.) aluminum sheet metal. The T50-2 consists of a motor and blower combination, 3 mylar air pads, a serpentuator mast, electrical master switch, operator's treadle ("dead man") switch, treadle bypass switch and a 115 Vac 60 cps umbilical connector with provisions for mounting operator's mast and safety yoke.

Applicability

The purpose of the proof procedure of the T50-2 is to verify basic vehicle design stability, operation, and performance as a low friction support for serpentuator simulations. With an operator securely positioned in the safety yoke and using the serpentuator or manual propulsion, the unit has the capability of performing docking, separation, and other difficult simulated space maneuvers.

Procedure

The T50-2 testing shall be performed in accordance with the Inspection and Test Instructions.

All test activities, data, and anomalies shall be documented in the Vehicle Log Book and the Acceptance Test Data Sheet (Form 962-K-6). Discrepancies found during the test shall be recorded on the Squawk Sheet (Form M-25-U) attached.

STA. NO.	INSPECTION & TEST INSTRUCTIONS			NUMBER	
INSP. DEPT.	TITLE Proof Procedure (Acceptance Test)			REL.	DATE
MFG. DEPT.	PART NAME Air Bearing Platform		PART NO.	REV.	DATE
MODEL NO. T50-2	SERIAL NO.	ORIGINATOR D. M. Rew	Q.E.L. APPROVAL	PAGE 1 OF 2	

NOTE: EXERCISE CARE TO AVOID DAMAGE TO AIR PADS

1. Verify instrumentation calibration due date and record.____________________

2. Physically examine the T50-2 for manufacturing discrepancies and/or shipping damage and record.______________

3. Weigh the T50-2 and record.___________

4. Measure and record motor case temperature (ambient) and record._____________

5. Place T50-2 on parking pad on air bearing floor.

Ø 6. Set air pad bypass valves to full open. (See Figure 1)

7. Connect the 115VAC 60 cycle umbilical; reel out sufficient electrical power cable to accommodate preprogrammed travel of air bearing platform so as to prevent unwanted automatic power cable retraction.

Ø 7a. Place mode switch in man mode position.

8. Close electrical master switch.

9. Close treadle bypass switch in order to actuate motor and blower, the unit is now floating on its air pads. Adjust and set variable speed control to provide necessary or adequate air flow.

Ø 10. Move T50-2 on air bearing floor surface and measure distance i.e. height of lift at each air pad from the floor to the bottom of the frame of the unit. Adjust air pad bypass valves individually to level patform and to obtain a clearance distance of not less than 1 ± 0.25 inches. Record clearance:_______, _______, ______

11. Apply 50 pound (unbalanced) load over each air pad sequentially and readjust air pad valves to attain balance.

12. Observe performance for stability and minimal drift.

13. Set serpentuator attach brackets to approximate height.

14. Attach serpentuator actuator.

15. Adjust inching mechanism to eliminate stress in serpentuator.

Form 966-A Rev. 1-64 NAA-S&ID

STA. NO.	INSPECTION & TEST INSTRUCTIONS			NUMBER	
INSP. DEPT.	TITLE Proof Procedure (Acceptance Test)			REL.	DATE
MFG. DEPT.	PART NAME		PART NO.	REV.	DATE
MODEL NO. T50-2	SERIAL NO.	ORIGINATOR D. M. Rew	Q.E.L. APPROVAL	PAGE 2 OF 2	

16. Open master switch to shut blower motor.

DO NOT MOUNT OR DISMOUNT FROM VEHICLE WHILE BLOWER MOTOR IS RUNNING

17. Offset operator weight with weights properly positioned over the center of gravity to make up a load of 200 lbs.

Ø 18. Place mode switch to unmanned position and close master switch.

19. Verify the air pad valves setting; see Paragraph 10 (above).

20. Repeat Paragraph 12 (above).

21. Move platforms across floor; record stress in serpentuator. Select floor area which represents average condition as indicated by stress charts. Mark floor area. (The Government will determine stress in the serpentuator with equipment and personnel available at time of proof testing.)

22. Return platforms to typical floor segment. Repeat Paragraph 15.

23. Perform serpentuator traverse 10 times, see Figure 2.

24. At midpoint and completion of test and after one (1) hour of operation measure

    a) Record motor case temperature rise (Temperature rise should not exceed 65°C.)

    b) Record stress at serpentuator attach points.

Form 966-A Rev. 1-64 NAA-S&ID

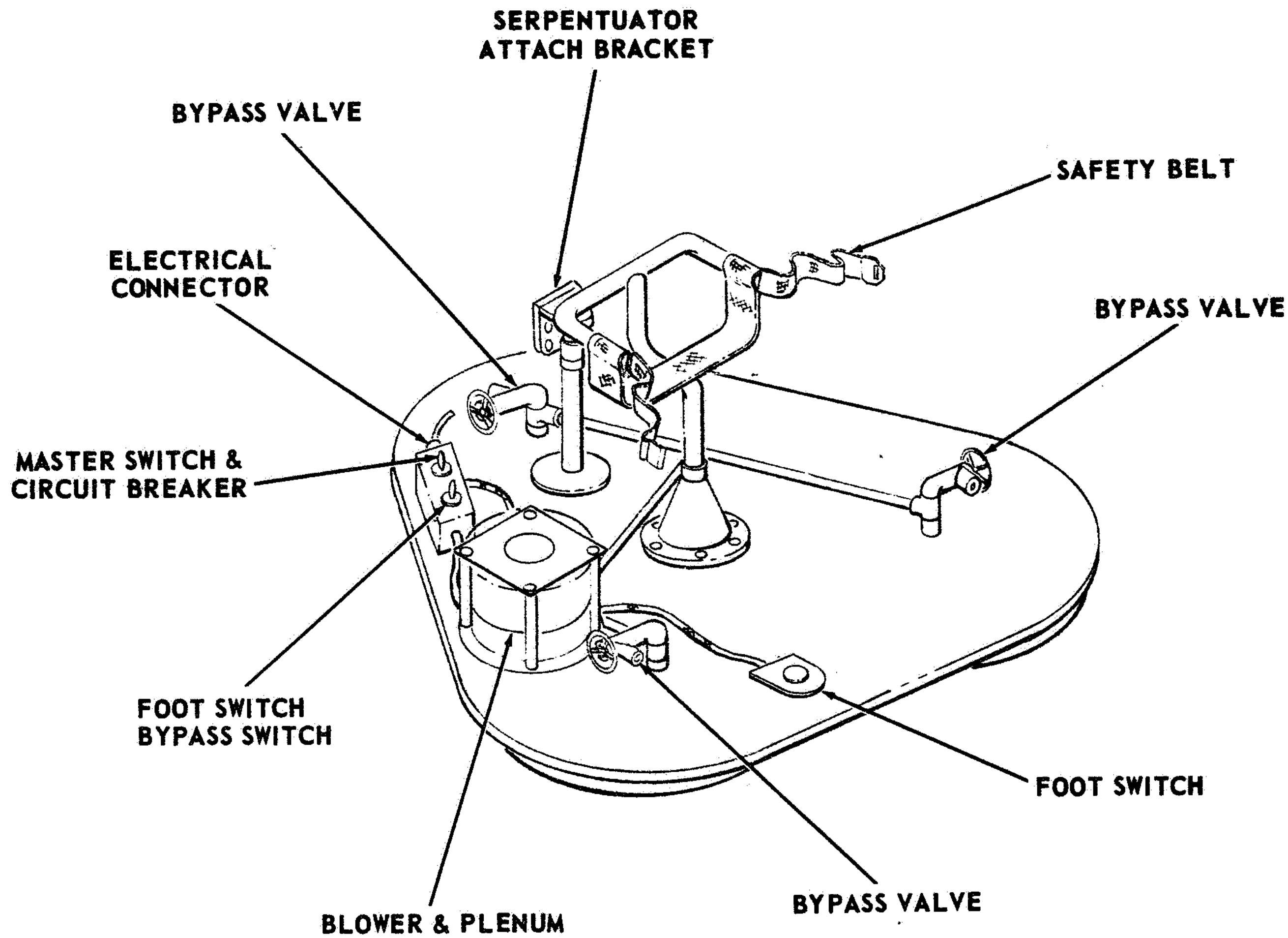

FIGURE E-1. MANNED AIR BEARING PLATFORM

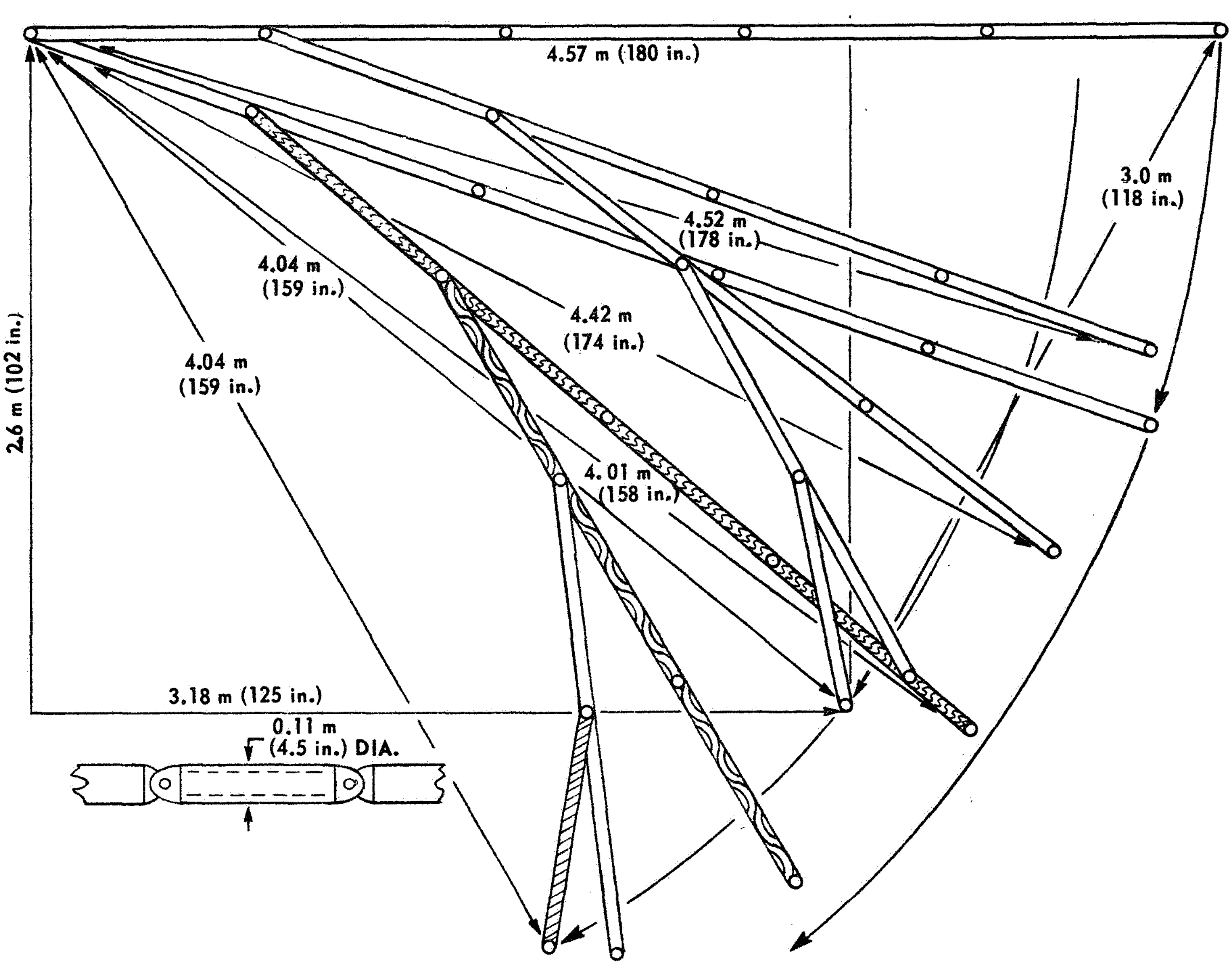

FIGURE E-2. SERPENTUATOR TRAVERSE PERFORMANCE

PAGE ____ OF ____

SYSTEM		MANUFACTURER	
PART NO.	MODEL NO.	SERIAL/LOT NO.	INSTALLED IN
TEST SPEC.	TEST LOC.	TEST DATE	DATE ACCEPTED

PARAGRAPH	NOMINAL (A) LOWER LIMIT (B)	TOLERANCE (A) UPPER LIMIT (B)	ACTUAL	PARAGRAPH	NOMINAL (A) LOWER LIMIT (B)	TOLERANCE (A) UPPER LIMIT (B)	ACTUAL

TEST EQUIPMENT USED				
NAME	MODEL	SERIAL NO.	CALIBRATION DUE	REMARKS

REMARKS CONCERNING TEST ARE CONTAINED ON PAGE ____ UNDER "NOTES AND COMMENTS"

NORTH AMERICAN AVIATION, INC.
SPACE and INFORMATION SYSTEMS DIVISION
12214 LAKEWOOD BLVD., DOWNEY, CALIFORNIA

SQUAWK SHEET

MAKE ENTRIES LEGIBLE – USE BALL POINT PEN WITH FIRM PRESSURE

MODEL	P/N	S/N	DEPT.	DATE			
SQWK NO.	SQWK ENT'D BY	DESCRIPTION OF DISCREPANCY AND ACTION TAKEN			CLEARED BY		
					Mech. and/or Lead.	Inspect. & Date	Cust. & Date
ACTION TAKEN							
ACTION TAKEN							
ACTION TAKEN							
ACTION TAKEN							

FORM M-25-U REV. 1-66

SHADED AREAS FOR CUSTOMER USE ONLY

Page Complete

INSP.

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APPENDIX F

ACCEPTANCE TEST PROCEDURE MODEL T50-2 AIR BEARING PLATFORM

APPENDIX F

ACCEPTANCE TEST PROCEDURE
MODEL T50-2 AIR BEARING PLATFORM

The data presented in Appendix F were extracted from a report prepared for NASA/MSFC by the Space and Information Division of North American Rockwell, Inc., dated August 21, 1967 (WN-0389).

Introduction

The air bearing platform (T50-2) was designed to support a nominal 90.6 kg (200 lb) and is equilateral 0.91 m (3 ft) triangular configuration composed of 0.0318 m (1.25 in.) tubing enclosed with 0.0032 m (0.125 in.) aluminum sheet metal. The T50-2 consists of a motor and blower combination, three (3) mylar air pads, a serpentuator mast, electrical master switch, operator's treadle ("dead man") switch, treadle bypass switch, and a 115 Vac 60 cps umbilical connector with provisions for mounting an operator's mast and safety yoke.

Applicability

The purpose of the Acceptance Test of the T50-2 is to verify basic vehicle design stability, operation, and performance as a low friction support for serpentuator simulations. With an operator securely positioned in the safety yoke and using the serpentuator or manual propulsion, the unit has the capability of performing docking, separation, and other difficult simulated space maneuvers.

Procedure

The T50-2 testing shall be performed in accordance with the Inspection and Test Instructions.

All test activities, data and anomalies shall be documented in the Vehicle Log Book and the Acceptance Test Sheet (Form 962-K-6). Discrepancies found during the test shall be recorded on the Squawk Sheet (Form M-25-U).

STA. NO.	INSPECTION & TEST INSTRUCTIONS			NUMBER
INSP. DEPT.	TITLE Acceptance Test			REL. DATE
MFG. DEPT.	PART NAME Air Bearing Platform		PART NO.	REV. DATE
MODEL NO. T50-2	SERIAL NO.	ORIGINATOR J. C. Fay	[redacted] APPROVAL J Welker	PAGE 2 OF 4

NOTE: EXERCISE CARE TO AVOID DAMAGE TO AIR PADS

INSP.

1. Verify instrumentation calibration due date and record.
2. Physically examine the T50-2 for manufacturing discrepancies and/or shipping damage and record.
3. Weigh the T50-2 and record.
4. Measure and record motor case temperature (ambient) and record.
5. Place T50-2 on parking pad on air bearing floor.
6. Set air pad bypass valves to mid-travel. (See Figure 1)
7. Connect the 115V AC 60 cycle umbilical; reel out sufficient electrical power cable to accommodate preprogrammed travel of air bearing platform so as to prevent unwanted automatic power cable retraction.
8. Close electrical master switch.
9. Close treadle bypass switch in order to actuate motor and blower, the unit is now floating on its air pads. Adjust and set variable speed control to provide necessary or adequate air flow.
10. Move T50-2 on air bearing floor surface and measure distance i.e. he height of lift at each air pad from the floor to the bottom of the frame of the unit. Adjust air pad bypass valves individually to level platform and to obtain a clearance distance of 1 $\pm$ 0.25 inches. Record clearance: ________ ________ ________
11. Apply 50 pound (unbalanced) load over each air pad sequentially and re-adjust air pad valves to attain balance.
12. Observe performance for stability and minimal drift.
13. Open master switch to shut off blower motor.

    DO NOT MOUNT OR DISMOUNT FROM VEHICLE WHILE BLOWER MOTOR IS RUNNING

14. Offset operator weight with weights properly positioned over the center of gravity to make up a load of 200 lbs.

STA. NO.	INSPECTION & TEST INSTRUCTIONS			NUMBER	
INSP. DEPT.	TITLE Acceptance Test			REL.	DATE
MFG. DEPT.	PART NAME Air Bearing Platform		PART NO.	REV.	DATE
MODEL NO. T50-2	SERIAL NO.	ORIGINATOR J. C. Fay	[redacted]. APPROVAL J Wolfson	PAGE 3 OF 4	

	INSP.
15. Place treadle bypass switch to operate position and close master switch.	
16. Actuate foot treadle (blower motor should operate).	
17. Verify the air pad valves setting; see Paragraph 10 (above).	
18. Repeat Paragraph 12 (above).	
19. At midpoint and completion of test and after one (1) hour of operation measure and record motor case temperature rise. (Temperature rise should not exceed 65°C.)	

APPENDIX G

"INSERP" TEST DATA

APPENDIX G

This appendix contains test data and strip chart results from evaluation of the "inserp" serpentuator.

The point scale in the "Ease of Working" column of the tables expressed as 1 to 10, easy to difficult respectively. All test subjects attempted to maintain a factor of 5.

It was determined during the first run that the maximum force setting was far superior to the others; therefore it was used exclusively for the remainder of the test.

TEST SUBJECT Robert Shafer

WEIGHT 88.4 kg (195 lb) HEIGHT 1.83 m (6.0 ft)

TEST SETUP Base Mode Shirtsleeve

Subjects Position	Force Setting	Ease of Working	Movement 0.698 Radian (seconds)	Movement 1.395 Radian (seconds)	Pumps Per Cycle	Maximum Force N (lb)	Maximum Force Typical Stroke N (lb)	Liner Velocity m/sec (ft/sec)
Prone	Maximum	5	41	29	40	33.4 (7.5)	24.4 (5.5)	0.219 (0.718)
Prone	Nominal							
Prone	Minimum							
Vertical	Maximum	5	47	27	51	33.8 (7.6)	26.7 (6.0)	0.234 (0.770)
Vertical	Nominal	5		40	58	32.0 (7.2)	20.0 (4.5)	0.158 (0.520)
Vertical	Minimum	5		70	156	28.4 (6.4)	14.7 (3.3)	0.091 (0.297)
Trailing	Maximum	5	38	25	47	34.7 (7.8)	27.6 (6.2)	0.254 (0.832)
Trailing	Nominal							
Trailing	Minimum							

TEST SUBJECT Jim Stevenson

WEIGHT 74.8 kg (165 lb) HEIGHT 1.83 m (6.0 ft)

TEST SETUP Base Mode Shirtsleeve

Subjects Position	Force Setting	Ease of Working	Movement 0.698 Radian (seconds)	Movement 1.395 Radian (seconds)	Pumps Per Cycle	Maximum Force N (lb)	Maximum Force Typical Stroke N (lb)	Liner Velocity m/sec (ft/sec)
Prone	Maximum	5	28	22	47	29.8 (6.7)	23.1 (5.2)	0.288 (0.945)
Prone	Nominal							
Prone	Minimum							
Vertical	Maximum	5	25	17	43	31.6 (7.1)	24.9 (5.6)	0.374 (1.227)
Vertical	Nominal							
Vertical	Minimum							
Trailing	Maximum	5	36	18	46	31.6 (7.1)	23.1 (5.2)	0.353 (1.158)
Trailing	Nominal							
Trailing	Minimum							

TEST SUBJECT Jim Stevenson

WEIGHT 74.8 kg (165 lb) HEIGHT 1.83 m (6.0 ft)

TEST SETUP Tip Mode Shirtsleeve

Subjects Position	Force Setting	Ease of Working	Movement 0.698 Radian (seconds)	Movement 1.395 Radian (seconds)	Pumps Per Cycle	Maximum Force N (lb)	Maximum Force Typical Stroke N (lb)	Liner Velocity m/sec (ft/sec)
Prone	Maximum	5	27	19	50	53.4 (12.0)	33.4 (7.5)	0.119 (0.390)
Prone	Nominal							
Prone	Minimum							
Vertical	Maximum	5	20	18	52	46.7 (10.5)	29.0 (6.5)	0.125 (0.410)
Vertical	Nominal							
Vertical	Minimum							
Trailing	Maximum	5	22	20	50	40.0 (9.0)	29.0 (6.5)	0.113 (0.370)
Trailing	Nominal							
Trailing	Minimum							

TEST SUBJECT Jim Stevenson

WEIGHT 74. 8 kg (165 lb) HEIGHT 1. 83 m (6. 0 ft)

TEST SETUP Base Mode Pressurized Suit

Subjects Position	Force Setting	Ease of Working	Movement 0. 698 Radian (seconds)	Movement 1. 395 Radian (seconds)	Pumps Per Cycle	Maximum Force N (lb)	Maximum Force Typical Stroke N (lb)	Liner Velocity m/sec (ft/sec)
Prone	Maximum	5	33	44	93	26. 7 (6. 0)	21.4 (4. 8)	0. 144 (0. 472)
Prone	Nominal							
Prone	Minimum							
Vertical	Maximum	5	28	28	59	34. 7 (7. 8)	24. 9 (5. 6)	0. 222 (0. 729)
Vertical	Nominal							
Vertical	Minimum							
Trailing	Maximum	5	29	22	57	28. 5 (6. 4)	23. 1 (5. 2)	0. 289 (0. 948)
Trailing	Nominal							
Trailing	Minimum							

TEST SUBJECT Jim Stevenson

WEIGHT 74. 8 kg (165 lb) HEIGHT 1. 83 m (6. 0 ft)

TEST SETUP Tip Mode Pressurized Suit

Subjects Position	Force Setting	Ease of Working	Movement 0. 698 Radian (seconds)	Movement 1. 395 Radian (seconds)	Pumps Per Cycle	Maximum Force N (lb)	Maximum Force Typical Stroke N (lb)	Liner Velocity m/sec (ft/sec)
Prone	Maximum	5	34	19	82	35. 6 (8. 0)	22. 2 (5. 0)	0. 119 (0. 390)
Prone	Nominal							
Prone	Minimum							
Vertical	Maximum	5	26	20	56	42. 3 (9. 5)	31. 1 (7. 0)	0. 113 (0. 370)
Vertical	Nominal							
Vertical	Minimum							
Trailing	Maximum	5	33	16	74	33. 4 (7. 5)	24. 5 (5. 5)	0. 137 (0. 449)
Trailing	Nominal							
Trailing	Minimum							

TEST SUBJECT Ron Brye

WEIGHT 90.7 kg (200 lb) HEIGHT 1.8 m (5.92 ft)

TEST SETUP Base Mode Shirtsleeve

Subjects Position	Force Setting	Ease of Working	Movement 0.698 Radian (seconds)	Movement 1.395 Radian (seconds)	Pump Per Cycle	Maximum Force N (lb)	Maximum Force Typical Stroke N (lb)	Liner Velocity m/sec (ft/sec)
Prone	Maximum	5	33	23	74	36.5 (8.2)	28.5 (6.41)	0.276 (0.906)
Prone	Nominal							
Prone	Minimum							
Vertical	Maximum	5	28	25	65	40.0 (9.0)	28.5 (6.41)	0.253 (0.830)
Vertical	Nominal							
Vertical	Minimum							
Trailing	Maximum	5	33	19	58	33.4 (7.5)	28.5 (6.41)	0.332 (1.089)
Trailing	Nominal							
Trailing	Minimum							

TEST SUBJECT Ron Brye

WEIGHT 90.7 kg (200 lb) HEIGHT 1.8 m (5.92 ft)

TEST SETUP Tip Mode Shirtsleeve

Subjects Position	Force Setting	Ease of Working	Movement 0.698 Radian (seconds)	Movement 1.395 Radian (seconds)	Pumps Per Cycle	Maximum Force N (lb)	Maximum Force Typical Stroke N (lb)	Liner Velocity m/sec (ft/sec)
Prone	Maximum	5	18	11	38	42.2 (9.5)	28.9 (6.5)	0.205 (0.672)
Prone	Nominal							
Prone	Minimum							
Vertical	Maximum	5	14	12	37	35.6 (8.0)	28.9 (6.5)	0.188 (0.616)
Vertical	Nominal							
Vertical	Minimum							
Trailing	Maximum	5	22	11	34	35.6 (8.0)	26.7 (6.0)	0.205 (0.672)
Trailing	Nominal							
Trailing	Minimum							

TEST SUBJECT Ron Brye

WEIGHT 90.7 kg (200 lb) HEIGHT 1.8 m (5.92 ft)

TEST SETUP Base Mode Pressurized Suit

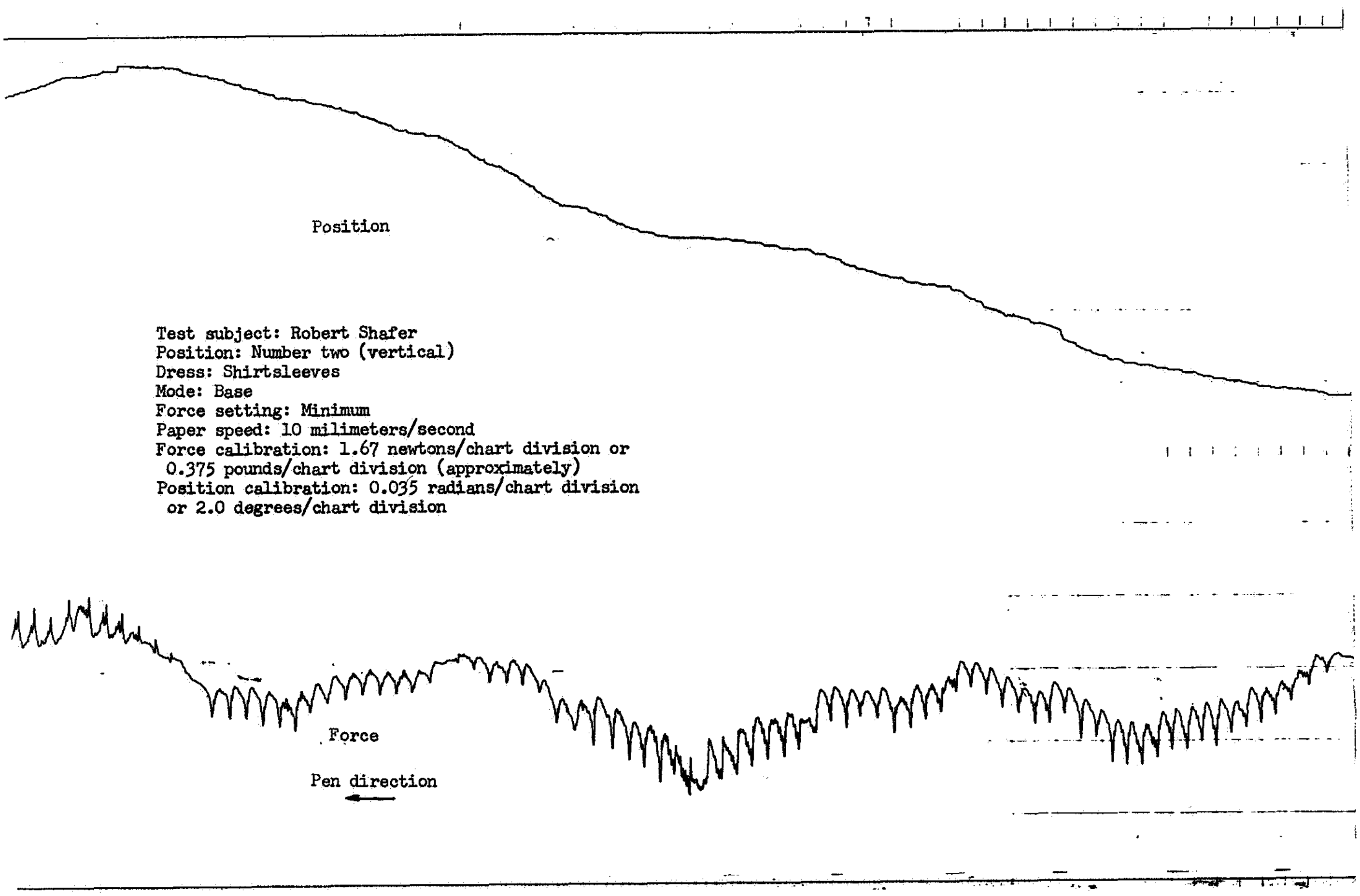
Subjects Position	Force Setting	Ease of Working	Movement 0.698 Radian (seconds)	Movement 1.395 Radian (seconds)	Pumps Per Cycle	Maximum Force N (lb)	Maximum Force Typical Stroke N (lb)	Liner Velocity m/sec (ft/sec)
Prone	Maximum	5	36	30	70	21.4 (4.8)	14.6 (3.3)	0.212 (0.696)
Prone	Nominal							
Prone	Minimum							
Vertical	Maximum	5	29	30	96	24.0 (5.4)	19.6 (4.4)	0.212 (0.696)
Vertical	Nominal							
Vertical	Minimum							
Trailing	Maximum	5	40	33	87	25.0 (5.6)	19.6 (4.4)	0.192 (0.630)
Trailing	Nominal							
Trailing	Minimum							

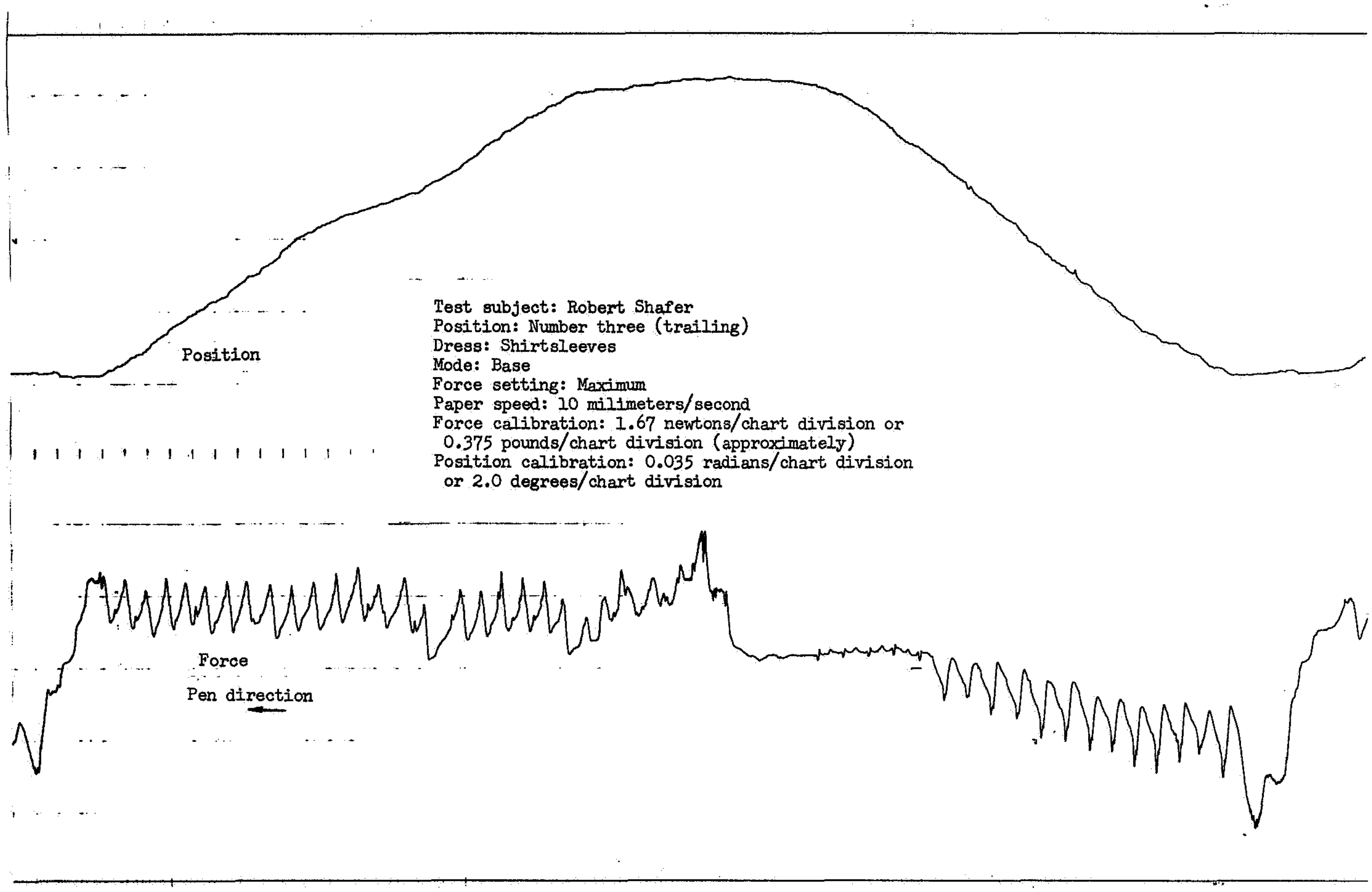
TEST SUBJECT Ron Brye

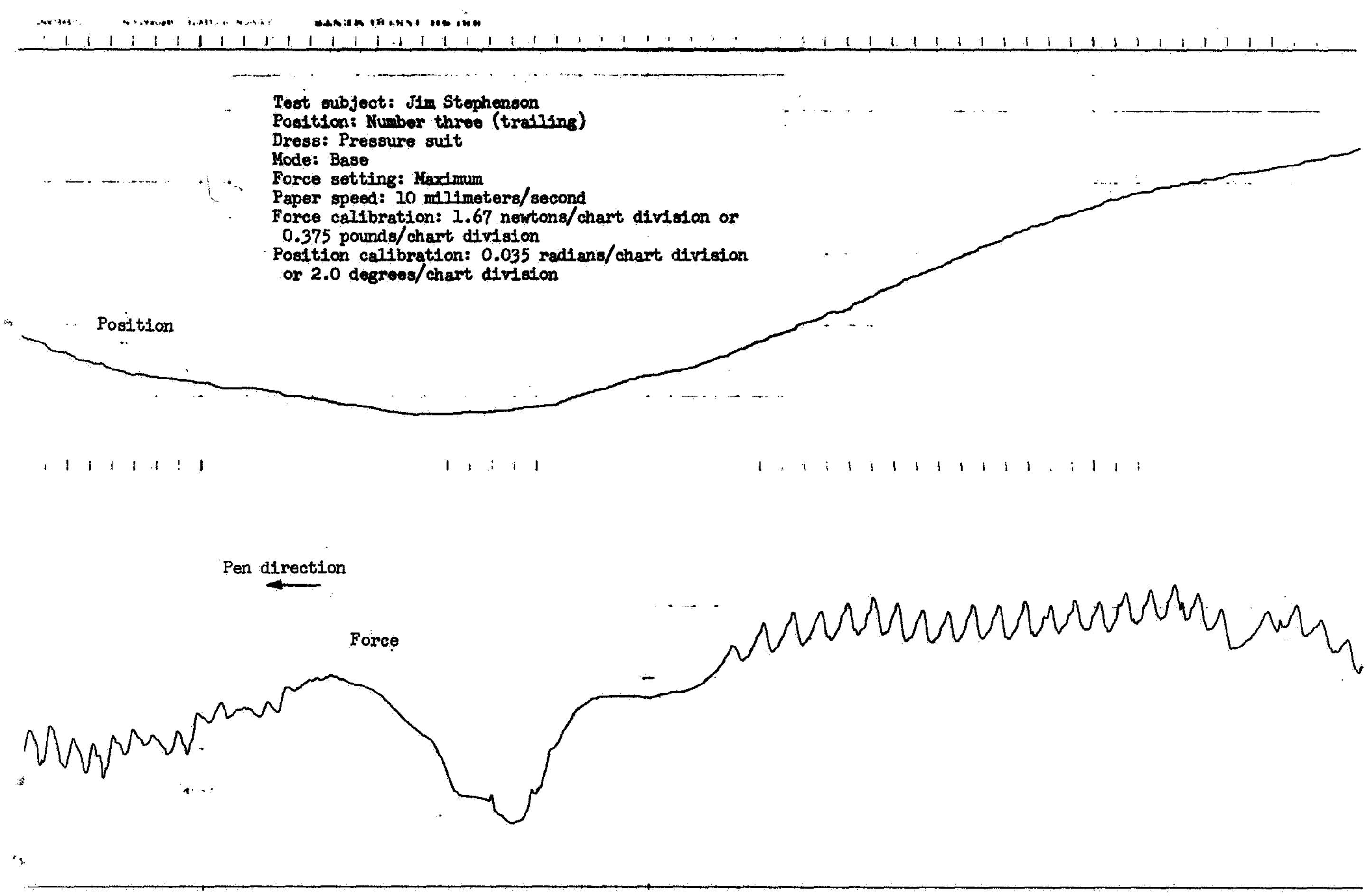
WEIGHT 90.7 kg (200 lb) HEIGHT 1.8 m (5.92 ft)

TEST SETUP Tip Mode Pressurized Suit

Subjects Position	Force Setting	Ease of Working	Movement 0.698 Radian (seconds)	Movement 1.395 Radian (seconds)	Pumps Per Cycle	Maximum Force N (lb)	Maximum Force Typical Stroke N (lb)	Liner Velocity m/sec (ft/sec)
Prone	Maximum	5	20	14	42	62.3 (14.0)	40.0 (9.0)	0.161 (0.529)
Prone	Nominal							
Prone	Minimum							
Vertical	Maximum	5	16	15	40	60.0 (13.5)	44.5 (10.0)	0.150 (0.493)
Vertical	Nominal							
Vertical	Minimum							
Trailing	Maximum	5	26	13	49	53.4 (12.0)	40.0 (9.0)	0.174 (0.570)
Trailing	Nominal							
Trailing	Minimum							


Position
Test subject: Robert Shafer
Position: Number two (vertical)
Dress: Shirtsleeves
Mode: Base
Force setting: Minimum
Paper speed: 10 milimeters/second
Force calibration: 1.67 newtons/chart division or
0.375 pounds/chart division (approximately)
Position calibration: 0.035 radians/chart division
or 2.0 degrees/chart division
Force
Pen direction


Position
Test subject: Robert Shafer
Position: Number three (trailing)
Dress: Shirtsleeves
Mode: Base
Force setting: Maximum
Paper speed: 10 milimeters/second
Force calibration: 1.67 newtons/chart division or
0.375 pounds/chart division (approximately)
Position calibration: 0.035 radians/chart division
or 2.0 degrees/chart division
Force
Pen direction


Test subject: Jim Stephenson
Position: Number three (trailing)
Dress: Pressure suit
Mode: Base
Force setting: Maximum
Paper speed: 10 milimeters/second
Force calibration: 1.67 newtons/chart division or 0.375 pounds/chart division
Position calibration: 0.035 radians/chart division or 2.0 degrees/chart division
Position
Pen direction
Force

TM X-53753

APPROVAL

COMPOSITE MECHANICAL SIMULATION

By H. T. Blaise

The information in this report has been reviewed for security classification. Review of any information concerning Department of Defense or Atomic Energy Commission programs has been made by the MSFC Security Classification Officer. This report, in its entirety, has been determined to be unclassified.

This document has also been reviewed and approved for technical accuracy.

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